Technical Report CERC-95-7
July 1995

US Army Corps of Engineers
Waterways Experiment Station

Rochester Harbor, New York, Design for Wave Protection

Coastal Model Investigation

by Robert R. Bottin, Jr., Hugh F. Acuff

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Prepared for U.S. Army Engineer District, Buffalo

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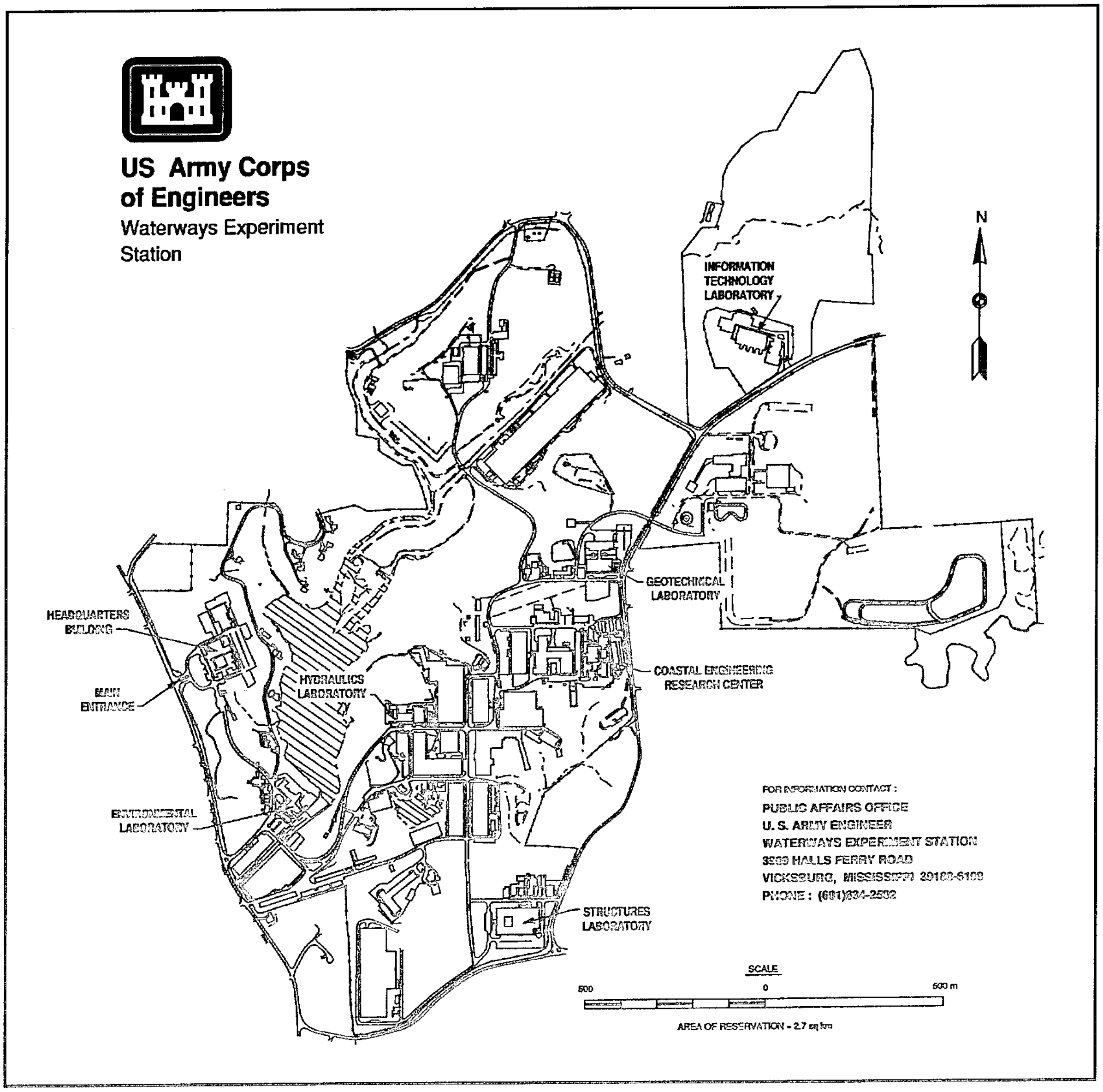
Final report

Prepared for U.S. Army Engineer District, Buffalo
Buffalo, NY 14207-3199



Waterways Experiment Station Cataloging-in-Publication Data

Bottin, Robert R.

Rochester Harbor, New York, design for wave protection : coastal model investigation / by Robert R. Bottin, Jr., Hugh F. Acuff ; prepared for U.S. Army Engineer District, Buffalo.

149 p. : ill. ; 28 cm. — (Technical report ; CERC-95-7)

Includes bibliographic references.

1. Harbors — New York (State) — Rochester — Design and construction. 2. Harbors —New York (State) — Rochester — Hydrodynamics — Models. 3. Hydraulic models. 4. Coastal engineering — New York (State) I. Acuff, Hugh F. II. United States. Army. Corps of Engineers. Buffalo District. III. U.S. Army Engineer Waterways Experiment Station. IV. Coastal Engineering Research Center (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; CERC-95-7.

TA7 W34 no.CERC-95-7

Contents

Preface

A request for a model investigation to study breakwater modifications at Rochester Harbor, New York, was initiated by the U.S. Army Engineer District, Buffalo (NCB), in a letter to the U.S. Army Engineer Division, North Central. Authorization for the U.S. Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), to perform the study was subsequently granted by Headquarters, U.S. Army Corps of Engineers. Funds were provided by the NCB on 28 April 1994 and 7 October 1994.

Model tests were conducted at WES during the period October 1994 through February 1995 by personnel of the Wave Processes Branch (WPB) of the Wave Dynamics Division (WDD), CERC, under the direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director of CERC, respectively; and under the direct guidance of Messrs. C. E. Chatham, Jr., Chief of WDD; and Dennis G. Markle, Chief of WPB. Tests were conducted by Messrs. Hugh F. Acuff, Civil Engineering Technician, and William G. Henderson, Computer Assistant, under the supervision of Mr. Robert R. Bottin, Jr., Project Manager. This report was prepared by Messrs. Bottin and Acuff.

Prior to the model investigation, Mr. Bottin attended a meeting at Rochester, New York, and visited the harbor site. The following personnel visited WES to observe model operation and participate in conferences during the course of the study:

Mr. Rich Gorecki	NCB
Mr. Ron Guido	NCB
Mr. Michael Mohr	NCB
Mr. Tom Bender	NCB
Mr. Doug Benson	City of Rochester
Mr. Graeme White	ESSROC Canada
Capt. James Leaney	Capt. m/v Stephen B. Roman, ESSROC
Mr. Paul Schmied	New York Department of Environmental Conservation

During the course of the study, liaison was maintained by means of conferences, telephone communications, and monthly progress reports. Mr. Ron Guido was Project Manager of the study for NCB, and Messrs. Mike Mohr and Tom Bender were technical points of contact.

Dr. Robert W. Whalin was Director of WES during model testing and the preparation and publication of this report. COL Bruce K. Howard, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic meters per second
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4536	kilograms
square feet	0.09290304	square meters
tons (2,000 lb, mass)	907.1848	kilograms

1 Introduction

The Prototype

Rochester Harbor is located on the southern shore of Lake Ontario (Figure 1) at the mouth of the Genesee River. The navigable portion of the river extends about 4.8 km (3 miles)[1] upstream from the lake. A dam upstream of the harbor regulates, to some degree, the flow conditions in the lower reaches of the river. The dam also traps sediments, and therefore, sedimentation in the river below the dam is relatively low in comparison to other harbors maintained by the Corps of Engineers at the mouths of rivers and creeks.

The existing Federal project at Rochester Harbor provides for parallel jetties at the mouth of the Genesee River located about 137 m (450 ft) apart. The east and west jetties are 823 and 925 m (2,699 and 3,036 ft) long, respectively, with crest elevations (el)[2] ranging from about +2.3 to +2.4 m (+7.4 to +8.0 ft). The jetties are stone-filled, vertical-walled, sheet-pile structures with concrete caps (U.S. Army Engineer District (USAED), Buffalo 1993). The project includes an authorized entrance channel depth of -7 m (-23 ft) between the jetties upstream to the railroad swing bridge, and a river channel depth of -6.4 m (-21 ft) extending southerly from the railroad bridge to the upstream limit of the project. The project is currently maintained to -7 m (-23 ft) in the lake approach entrance channel end (-6.4 m (-21 ft)) in the river channel. An aerial photograph of the harbor entrance is shown in Figure 2.

Historically, Rochester Harbor has experienced both commercial and recreational activities. There have been shipyards, foundries, railroad

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1 Units of measurement in the text of this report are shown in SI units, followed by non-SI units in parentheses. Also, a table of factors for converting non-SI units of measurement used in plates, figures, photos, and tables in this report to SI units is presented on page vi.

2 All elevations cited herein are in meters (feet) referred to low water datum (LWD). LWD on Lake Ontario is 74 m (242.8 ft) above the International Great Lakes Datum (IGLD) of 1955, 74.2 m (243.3 ft) above IGLD of 1985.

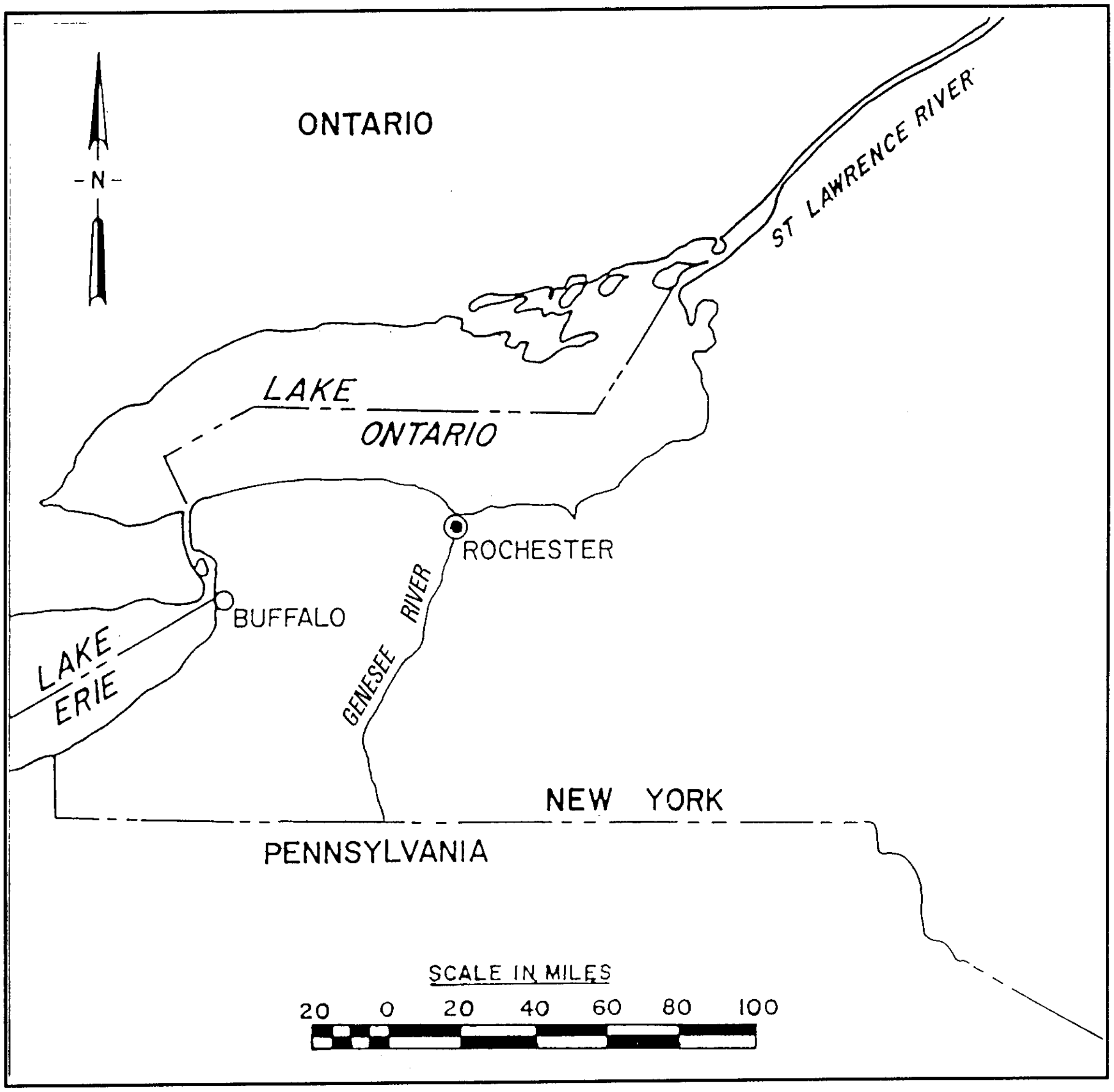

Figure 1. Project location

terminals, yacht clubs, the former Rochester-Monroe County Port Authority, a resort, and an amusement park located in this reach of the river over the years. Currently, the lower river is predominately bordered by marinas, yacht clubs, the U.S. Coast Guard station, and city-owned land consisting of a boat launching ramp and the Ontario Beach Park on the west bank at the lakefront. There are approximately 900 permanent-based slips in seven private marinas. In addition, there are four launch ramps with seven launch ramp lanes. Fishing is available on both the east and west jetties.

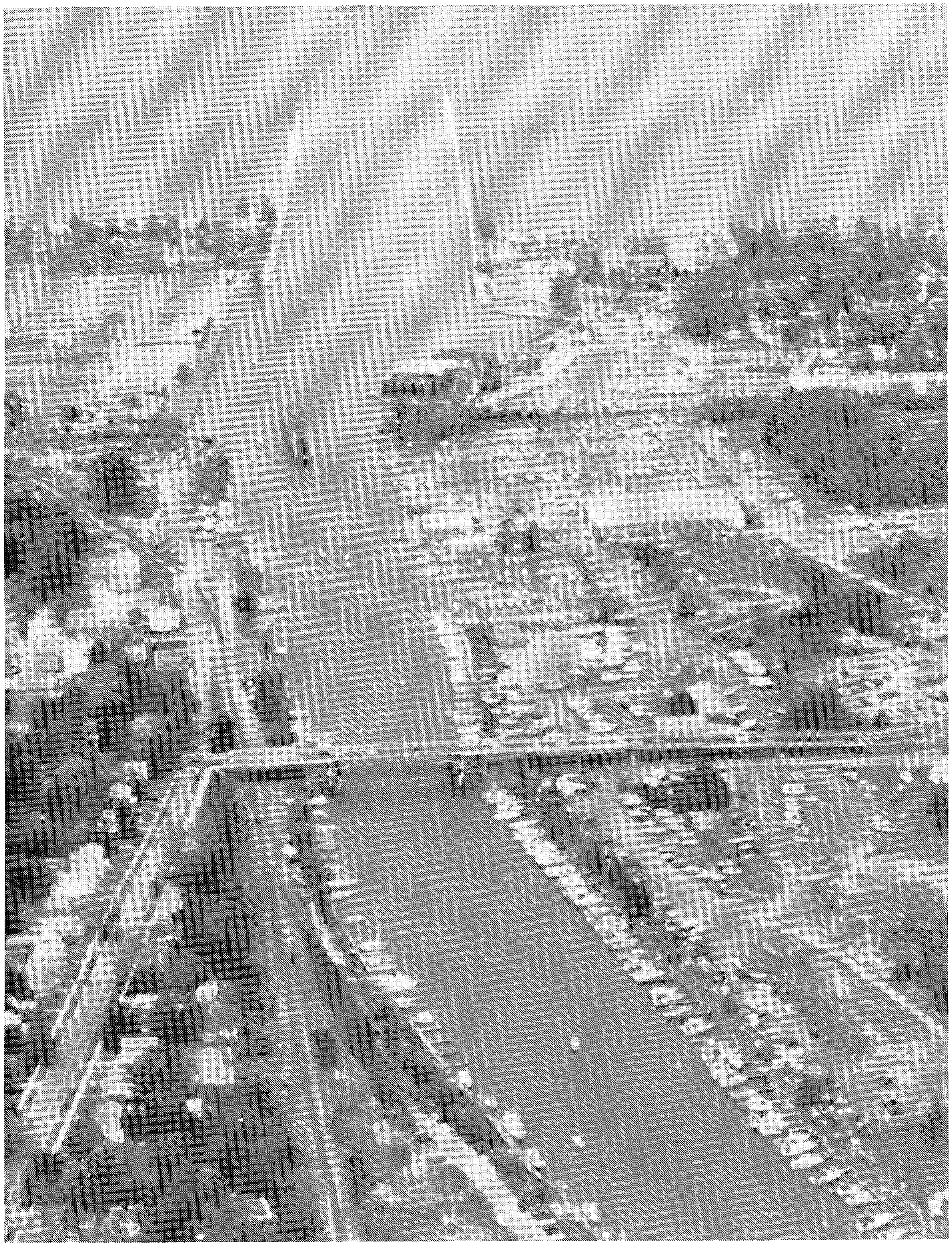

Figure 2. Aerial view of harbor

The Problem

Rochester Harbor is susceptible to excessive wave action during storms with strong northeast winds. The parallel sheet-pile jetties extend northeasterly into Lake Ontario, and provide little protection from these storms. In fact, they tend to channel wave energy further upstream. Due to the vertical-walled shoreline features in the harbor, wave conditions may be worse, in some areas, than those in the lake because of wave reflections (USAED, Buffalo 1993).

Rochester Harbor's ability to function as an adequate harbor of refuge is in question during northeasterly storms. Existing marinas are restricted from mooring additional boats during these storms, so small craft tend to moor along the jetties. Consequently, due to wave action, boats that use the harbor for refuge often experience damage. Existing marinas also experience damage to their facilities and customer's vessels and expend significant resources tending vessels during storms. In addition to storm damage, the marinas' business is restricted because some docks cannot be used because existing slips must be wider to afford adequate protection during northeasterly storms. This has reduced the number of slips which can be operated.

The Coast Guard, which operates a station on the east bank of the Genesee River, has had to move emergency craft upstream to the west side of the river because of wave problems in the lower river. This has significantly increased response time for emergencies because personnel must now drive across a swing bridge to get to the rescue boat. This has resulted in response times as long as 1 hr. The primary commercial users of the harbor, cement boats, will not enter or leave the harbor during northeasterly storms. While these delays do not appear to be significant, they illustrate the seriousness of the problem.

The City of Rochester has developed a plan for a $100-million waterfront revitalization along the lower reaches of the river (USAED, Buffalo 1993). The plan includes development of a small boat harbor in an excavated area of the former Port Authority site with 75 transient and 75 permanent slips and construction of 230 additional slips along the west bank of the river. However, wave action is so severe in this area that the plan is not feasible without additional protection. Development is keyed to construction of measures that would reduce wave energy. City representatives have indicated that such developments are critical to the continued economic vitality of Rochester. City studies indicate that there is significantly more demand for berths for recreational craft than are currently available.

Purpose of the Model Study

At the request of the USAED, Buffalo, a physical coastal hydraulic model investigation was initiated by the U.S. Army Engineer Waterways Experiment Station (WES) to:

a. Study wave, current, river flow, and shoaling conditions for the existing harbor configuration.

b. Determine if the proposed improvements would provide acceptable wave, current, river flow, and shoaling conditions in the harbor.

c. Develop remedial plans for the alleviation of undesirable conditions as found necessary.

d. Determine if suitable design modifications to the proposed plans could be made to significantly reduce construction costs without sacrificing the desired level of protection.

Wave Height Criterion

Validated design criteria have not yet been developed for ensuring satisfactory navigation and mooring conditions in small-craft harbors during attack by storm waves. For this study, however, the Buffalo District specified that for an improvement plan to be acceptable, maximum significant wave heights were not to exceed 0.3 m (1.0 ft) in the existing and proposed mooring areas of the harbor and lower reaches of the river for wave conditions with a 20-yr recurrence occurring during the recreational boating season (April - October).

2 The Model

Design of Model

The Rochester Harbor model (Figure 3) was constructed to an undistorted linear scale of 1:75, model to prototype. Scale selection was based on the following factors:

a. Depth of water required in the model to prevent excessive bottom friction.

b. Absolute size of model waves.

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Available wave-generating and wave-measuring equipment.

f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Model-Prototype Dimension[1]	Scale Relations
Length	L	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5,625$
Volume	L^3	$V_r = L_r^3 = 1:421,875$
Time	T	$T_r = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$
Roughness (Manning's coefficient, n)	$L^{1/6}$	$n_r = L_r^{1/6} = 1:2.054$
Discharge	L^3/T	$Q_r = L_r^{5/2} = 1:48,714$

[1] Dimensions are in terms of length (L) and time (T).

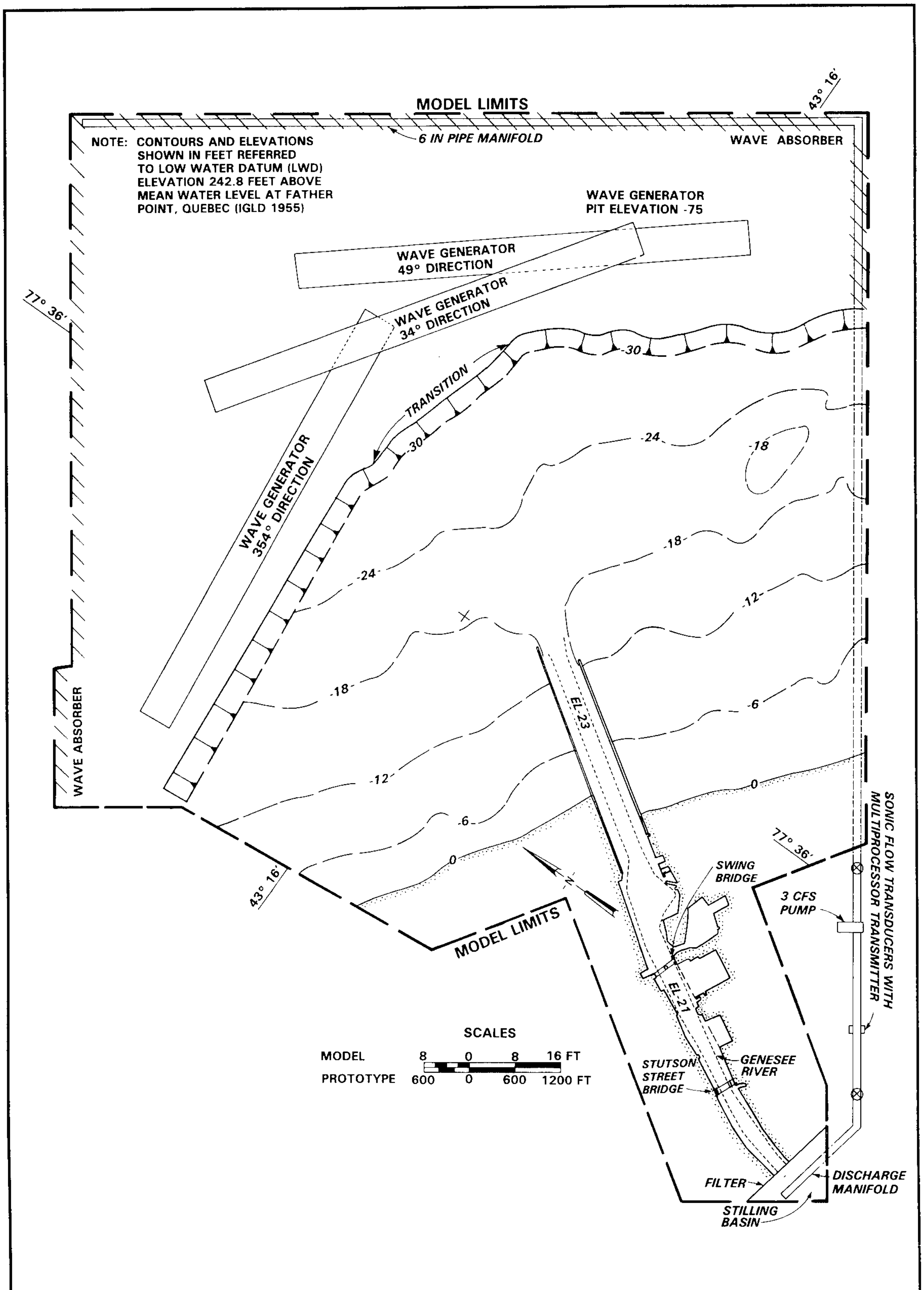

Figure 3. Model layout

The proposed improvement plans for Rochester Harbor included the use of rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, transmission and absorption of wave energy were given close consideration during design of the 1:75-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (Le Méhauté 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection, wave-absorption, and wave-transmission characteristics. In past investigations at WES (Dai and Jackson 1966, Brasfeild and Ball 1967), this adjustment was made by determining the wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at Rochester Harbor, it was determined that a close approximation of the correct wave-energy transmission characteristics could be obtained by increasing the size of the rock used in the 1:75-scale model to approximately one and a half times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the Rochester Harbor model, the rock sizes were computed linearly by scale, then multiplied by 1.5 to determine the actual sizes to be used in the model.

The values of Manning's roughness coefficient n used in the design of the river channel were calculated from water-surface profiles of known discharges in the prototype. From these computations and experience, an n value of 0.025 was selected for use in the main river channel. In addition, based on experience, an n value of 0.050 was selected for overbank roughness. Therefore, based on previous WES investigations (Miller and Peterson 1953, Cox 1973), the model river areas from the marinas extending upstream were given finishes that would represent prototype n values of 0.025 and 0.050.

Ideally, a quantitative, three-dimensional, movable-bed model investigation would best determine the effects of structures with regard to sediment deposition in the river entrance. However, this type of model investigation is difficult and expensive to conduct, and each area in which such an investigation is contemplated must be carefully analyzed. In view of the complexities involved in conducting movable-bed model studies and due to limited funds and time for the Rochester Harbor project, the model was molded in cement mortar (fixed-bed) at an undistorted scale of 1:75, and a tracer material was obtained to qualitatively determine riverine sediment patterns in the harbor entrance.

The Model and Appurtenances

The model reproduced approximately 1,372 m (4,500 ft) of the lower reaches of the Genesee River, the jettied harbor entrance, about 914 m (3,000 ft) of the New York shoreline on each side of the harbor entrance, and bathymetry in Lake Ontario to an offshore depth of 9.1 m (30 ft) with a sloping transition to the wave generator pit elevation of -22.9 m (-75 ft). The total area reproduced in the model was approximately 1,810 sq m (19,500 sq ft), representing about 10.1 sq km (3.9 sq miles) in the prototype. A general view of the model is shown in Figure 4. Vertical control for model construction was based on LWD, el 74 m (242.8 ft) above mean water level at Father Point, Quebec (IGLD 1955). Horizontal control was referenced to a local prototype grid system.

Model waves were generated by a 24.4-m-long (80-ft-long), unidirectional spectral, electrohydraulic, wave generator with a trapezoidal-shaped plunger. The vertical motion of the plunger was controlled by a computer-generated command signal, and movement of the plunger caused a periodic displacement of water which generated the required test waves. The wave generator was mounted on retractable casters which enabled it to be positioned to generate waves from required directions.

A water circulation system (Figure 3), consisting of a 15.2-cm (6-in.), perforated-pipe water-intake manifold, a 0.08-cms (3-cfs) pump, and sonic flow transducers with a multiprocessor transmitter, was used in the model to reproduce steady-state flows through the river channel that corresponded to selected prototype river flows. The magnitudes of river currents were measured by timing the progress of weighted floats over known distances.

An Automated Data Acquisition and Control System, designed and constructed at WES (Figure 5), was used to generate and transmit control signals, monitor wave generator feedback, and secure and analyze wave data at selected locations in the model. Through the use of a microvax computer, the electrical output of parallel-wire, capacitance-type wave gauges, which varied with the change in water-surface elevation with respect to time, were recorded on magnetic disks. These data were then analyzed to obtain the parametric wave data.

A 0.6-m (2-ft) (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

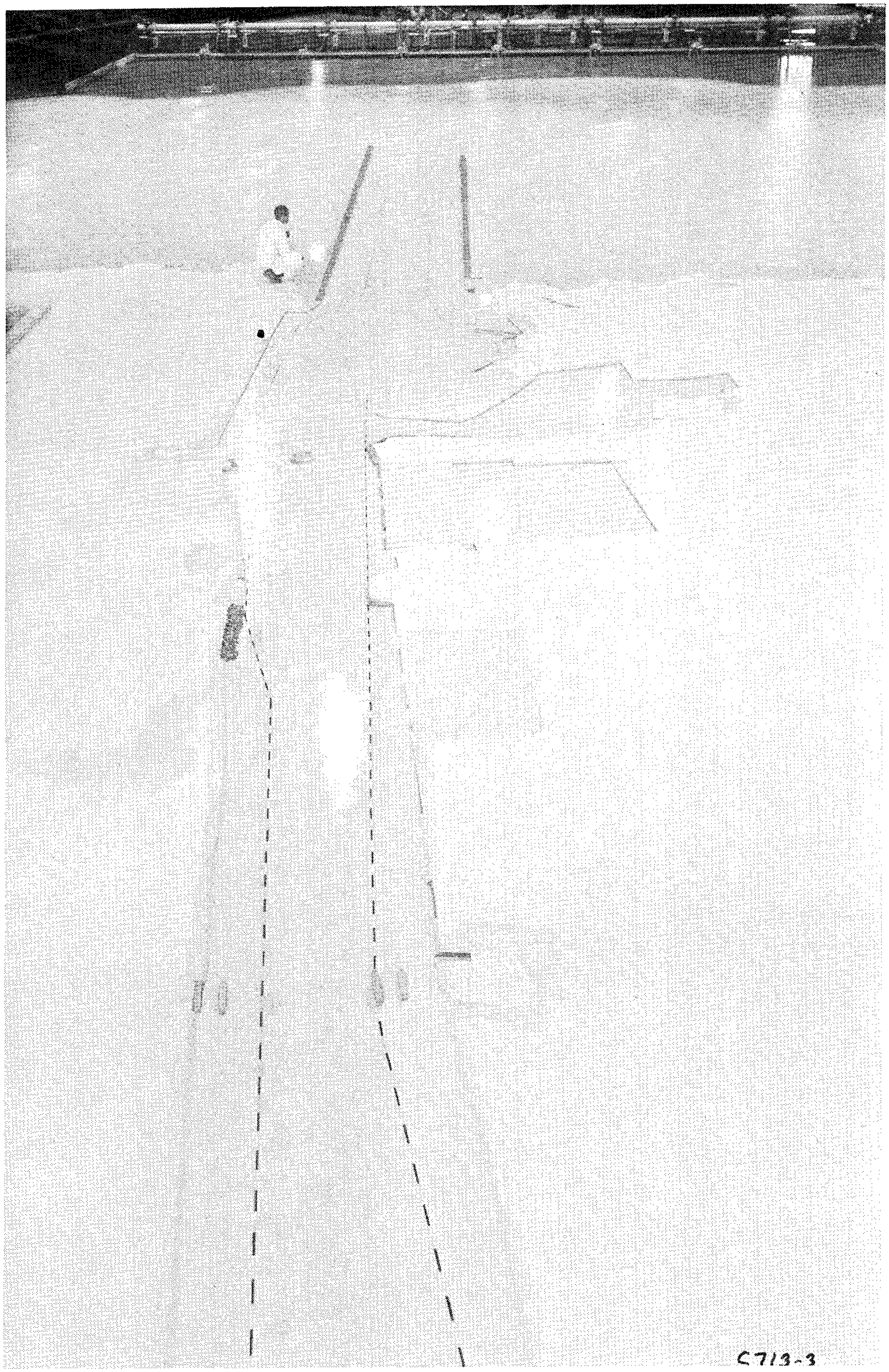

Figure 4. General view of model

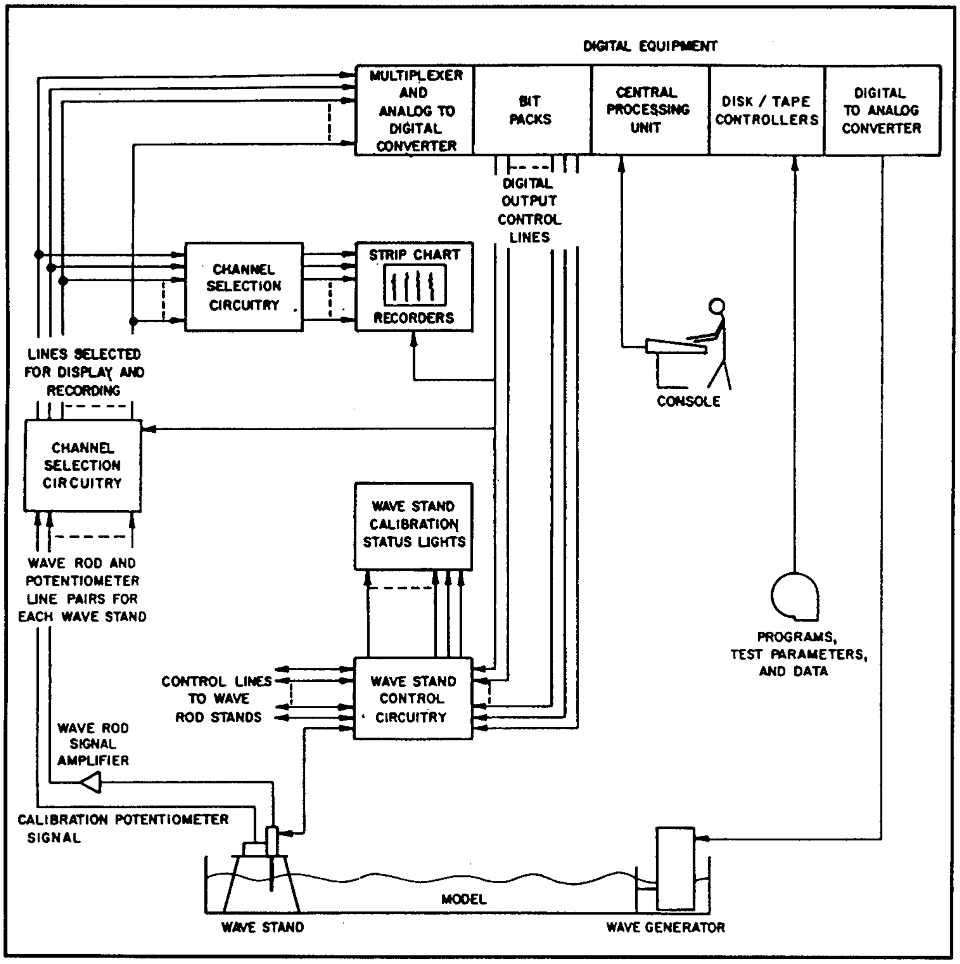

Figure 5. Automated Data Acquisition and Control System

Design of Tracer Material

As discussed previously, a fixed-bed model was constructed and a tracer material designed and prepared to qualitatively determine movement and deposition of sediment in the Rochester Harbor entrance. Tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation or model law among the four basic scale ratios, i.e., the horizontal scale λ; the vertical scale μ; the sediment size ratio η_D; and the relative specific weight ratio η_γ. These relations were determined experimentally using a wide range of conditions and bottom materials.

Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:75 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of Rochester Harbor was undistorted to allow accurate reproduction of short-period wave and current patterns, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.20 mm; specific gravity = 2.65) and assuming

the horizontal scale to be in similitude (i.e., 1:75), the median diameter for a given vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented the movement of prototype sand. Therefore, quantities of crushed coal (specific gravity = 1.30; median diameter, D_{50} = 0.52 mm) were selected for use as a tracer material throughout the model investigation.

3 Test Conditions and Procedures

Selection of Test Conditions

Still-water level

Still-water levels (swl's) for harbor wave action models are selected so that various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include refraction of waves in the project area, overtopping of harbor structures by waves, reflection of wave energy from various structures, and transmission of wave energy through porous structures.

Water levels on the Great Lakes vary from year to year and month to month. In many locations, the water level can fluctuate daily or hourly. Since 1860, continuous records of water levels on the Great Lakes have been recorded and maintained. Typical variations of the Lakes consist of high stages in the summer months and low stages in the winter months. For Lake Ontario, the higher levels usually occur in June and the lower levels in January. During the period of record (1860-1952), the average level of Lake Ontario was +0.6 m (+2.0 ft) (Saville 1953). From 1860 to the present, the highest 1-month average level of +1.6 m (+5.26 ft) occurred in June 1952, and the lowest 1-month average level of -0.4 m (-1.37 ft) occurred in December 1934. The seasonal variation in the mean monthly level of Lake Ontario usually ranges between 0.3 and 0.6 m (1 and 2 ft), with an average variation of 0.55 m (1.8 ft).

Seasonal and longer variations in the levels of the Great Lakes are caused by variations in precipitation and other factors that affect the actual quantities of water in the lakes. Wind tides and seiches are relatively short-period fluctuations caused by the tractive force of wind blowing over the water surface and by differential barometric pressures and are superimposed on the longer period variations in the lake level. Large short-period rises in local water levels are associated with the most severe storms, which generally occur in the winter when the lake level is usually

low; thus the probability that a high lake level and a large wind tide or seiche will occur simultaneously is relatively small.

Still-water levels of +0.76 and +1.43 m (+2.5 and +4.7 ft) were selected by the Buffalo District for use during model testing. The lower value (+0.76 m (+2.5 ft)) represented an average summer water level and was used in conjunction with test waves that occur during the boating season (April through October), and the higher value (+1.43 m (+4.7 ft)) represented a lake level with a 10-year recurrence interval and was used with all-season test waves. The swl of +0.76 m (+2.5 ft) also was used while obtaining river flow data through the Genesee River between the jetties and in the lower reaches of the river.

Factors influencing selection of test wave characteristics

In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select heights, periods, and directions for the test waves that will allow a realistic test of proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum significant wave that can be generated by a given storm depend on wind speed, length of time that wind of a given speed continues to blow, and distance over water (fetch) which the wind blows. Selection of test wave conditions entails evaluation of such factors as:

a. Fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can approach the problem area.

b. Frequency of occurrence and duration of storm winds from the different directions.

c. Alignment, size, and relative geographic position of the navigation structures.

d. Alignments, lengths, and locations of the various reflecting surfaces in the area.

e. Refraction of waves caused by differentials in depth in the area lakeward of the site, which may create either a concentration or a diffusion of wave energy.

Deepwater wave data

Measured prototype wave data covering a sufficiently long duration from which to base a comprehensive statistical analysis of deepwater wave conditions for the Rochester Harbor area were not available. However, statistical wave hindcast estimates representative of this area were available from Resio and Vincent (1976). This hindcast was developed for 17 points along the U.S. Lake Ontario shore using historical wind data from three climatological stations. Significant wave heights and peak wave period were calculated for 5-, 10-, 20-, 50-, and 100-year return periods for three wave approach angles to shore. The three angle classes are shown in Figure 6 and defined as viewed from an observer standing on shore as: (a) Angle Class 1 - mean wave approach angle greater than 30 deg to the right of normal to shore, (b) Angle Class 2 - mean wave approach angle within 30 deg to either side of normal to shore, and (c) Angle Class 3 - mean wave approach angle greater than 30 deg to the left of normal to shore.

This hindcast study was updated by Reinhard, Driver, and Hubertz (1991). In the updated report, 32 years (1956-1987) of hindcast wind and

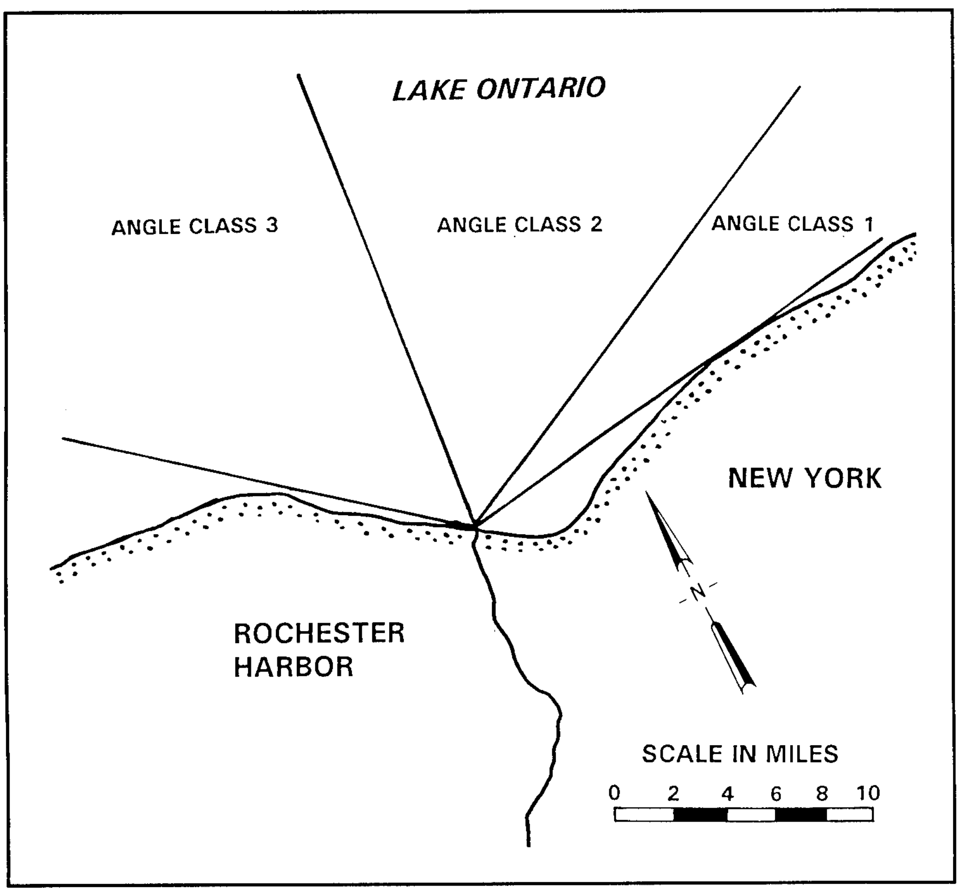

Figure 6. Wave hindcast angle classes

wave information are summarized for locations along the U.S. shoreline of Lake Ontario in four data products: percent occurrence tables, wave rose diagrams, mean and largest wave heights, and 32-year statistics tables and return period tables. The complete wave hindcast is available at 3-hr intervals for the period of record. Deepwater wave hindcast data for the Rochester Harbor model was selected from results of these two studies.

Wave transformation

When waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. When the refraction coefficient K_r is determined, it is multiplied by the shoaling coefficient K_s and gives a conversion factor of deepwater wave heights to shallow-water values. The shoaling coefficient, a function of wave length and water depth, can be obtained from the *Shore Protection Manual* (1984).

For this study, deepwater wave data were converted to shallow-water values by the Buffalo District through the use of two wave transformation techniques. Initially, wave characteristics were transformed from deep water to the -9.1-m (-30-ft) contour (approximate location of wave generator in model) using the computer program WAVETRAN (Gravens, Kraus, and Hanson 1991). The program is based upon the TMA (Texdl-MARSEN-ARSLOE) spectral transformation of waves, with no additional energy input from wind, and straight and parallel bottom contours. Wave sheltering from nearby land masses and shoals can be determined. Transformation of deepwater hindcast data then was performed using the method of Goda (Seelig and Ahrens 1980). This method is intended for open sections of coast with continuously shallowing depth contours. Design curves were developed to compute refraction coefficients and nearshore wave breaking. Refraction calculations are based on the energy-weighted superposition of refraction coefficients obtained from linear theory and include directional spreading of wave energy. This method is intended for the case of straight parallel bottom contours. A comparison of the two wave transformation methods revealed that shallow-water wave characteristics were lower for WAVETRAN than for the method of Goda. For design purposes, the larger transformation values, which more closely agreed with those obtained using Goda's method, were selected for use in this study.

Selection of test waves

Based on transformation of hindcast data, waves approaching Rochester Harbor from angle class 1 (Figure 6) were less than 1.2 m (4.0 ft) due to extensive refraction and wave sheltering and were eliminated from

consideration for testing. Although waves from angle classes 2 and 3 were possible, initially only wave conditions from the 60-deg band of angle class 2 were selected for testing. It was assumed that waves approaching from 34 deg (directly down the axis of the channel) would result in the worst wave conditions in the harbor. Thus, preliminary tests of alternative design concepts were initially conducted for waves with 2-, 5-, and 20-year recurrence intervals from 34 deg, as shown below. All incident waves were measured at the -9.1-m (-30-ft) contour in the model.

Wave Direction, deg	Initial Test Waves		Recurrence Interval years
	Period, sec	Height, m (ft)	
Recreational Navigation Season, swl = +0.76 m (+2.5 ft)			
34	5.4	1.58 (5.2)	2
	5.8	2.16 (7.1)	5
	6.4	2.77 (9.1)	20
All Season, swl = +1.43 m (+4.7 ft)			
34	6.0	2.10 (6.9)	2
	6.3	2.56 (8.4)	5
	6.7	3.05 (10.0)	20

After preliminary tests were conducted for the alternative initial alternative design concepts, the Buffalo District conducted a sensitivity analysis relative to wave conditions and recurrence intervals. It was noted that most test waves from angle class 2 actually approached the harbor from 15 deg east of the axis of the entrance channel (i.e., 49 deg). Considering this analysis and wave conditions from angle class 3 (354 deg), selected (cost-effective) design alternatives were subjected to the following refined wave conditions.

Wave Direction, deg	Refined Test Waves		Recurrence Interval years
	Period, sec	Height, m (ft)	
Recreational Navigation Season, swl = +0.76 m (+2.5 ft)			
49	5.8	2.16 (7.1)	5
	6.4	2.77 (9.1)	20
	6.7	3.05 (10.0)	50
34	5.0	1.58 (5.2)	5
	5.8	2.19 (7.2)	20
	6.1	2.53 (8.3)	50
354	5.7	1.83 (6.0)	5
	6.3	2.26 (7.4)	20
	6.5	2.44 (8.0)	50
			(Continued)

Wave Direction, deg	Refined Test Waves		Recurrence Interval years
	Period, sec	Height, m (ft)	
All Season, swl = +1.43 m (+4.7 ft)			
49	6.3	2.56 (8.4)	5
	6.7	3.05 (10.0)	20
	7.0	3.23 (10.6)	50
34	5.4	1.98 (6.5)	5
	6.3	2.59 (8.5)	20
	6.6	2.96 (9.7)	50
354	6.0	2.10 (6.9)	5
	6.4	2.32 (7.6)	20
	6.5	2.44 (8.0)	50

Unidirectional wave spectra were generated (based on TMA parameters) for the selected test waves and used throughout the model investigation. Plots of a typical wave spectra are shown in Figure 7. The solid line represents the desired spectra, while the dashed line represents the spectra reproduced in the model. A generic TMA gamma function of 3.3 was used to determine the spread of the spectra. The larger the gamma value, the sharper the peak in the energy distribution curve. A typical wave time series is shown in Figure 8, which depicts water surface elevation η versus time. Selected test waves were defined by significant wave height, the average height of the highest one-third of the waves or H_s. In deep water, H_s is very similar to H_{mo} (energy-based wave) where $H_{mo} = 4\ (E)^{1/2}$, and E equals total energy in the spectra which is obtained by integrating the energy density spectra over the frequency range.

River discharges

River discharge data for the Genesee River were available from water discharge records during the period 1952 - 1993. Based on these data the following river discharges and recurrence intervals were selected for testing by the Buffalo District and simulated in the model.

Discharge, Q, cms (cfs)	Recurrence Interval, years
510 (18,000)	2
685 (24,200)	10
885 (31,300)	100

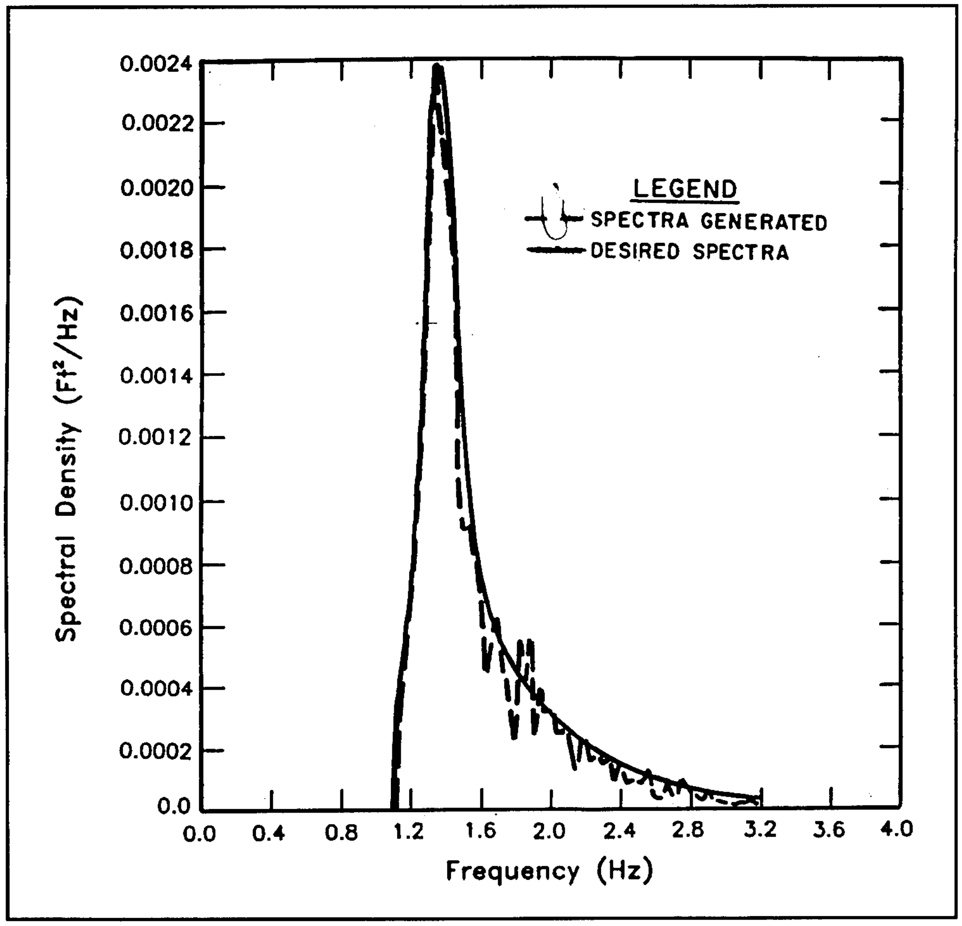

Figure 7. Typical energy density versus frequency plots (model terms) for a wave spectra; 6.4-sec, 9.1-ft test waves

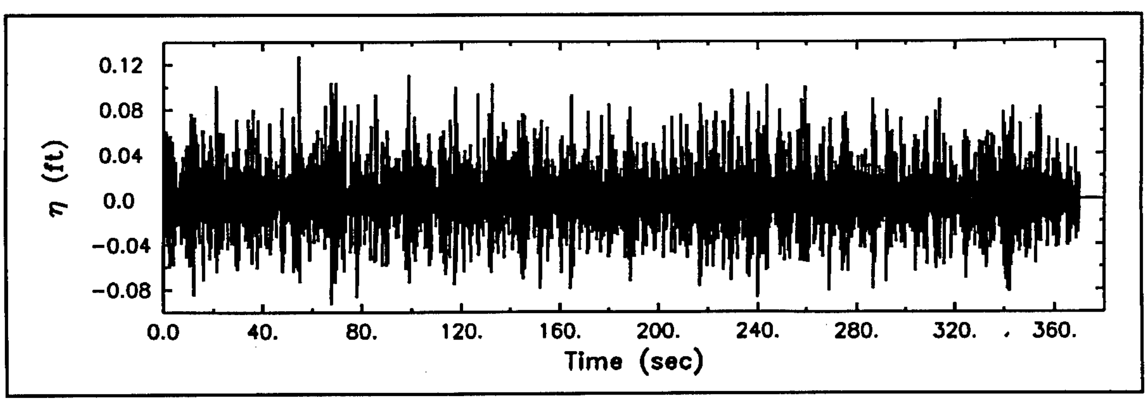

Figure 8. Typical model wave train time series, 6.4-sec, 9.1-ft test waves

Analysis of Model Data

Relative merits of the various plans tested were evaluated by:

a. Comparison of wave heights at selected locations in the model.

b. Comparison of water-surface profiles and river current patterns/velocities.

c. Comparison of riverine sediment tracer movement and deposits.

d. Visual observations and wave pattern photographs.

In the wave-height data analysis, the average height of the highest one-third of the waves (H_s), recorded at each gauge location, was computed. All wave heights then were adjusted by application of Keulegan's equation[1] to compensate for excessive model wave height attenuation due to viscous bottom friction. From this equation, reduction of model wave heights (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel, and model data can be corrected and converted to their prototype equivalents. Water surface elevations were obtained using point gauges at selected locations in the river channel, and river current velocities were secured by timing the progress of a weighted float over a known distance.

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[1] G. H. Keulegan, 1950, "The Gradual Damping of a Progressive Oscillatory Wave with Distance in a Prismatic Rectangular Channel," Unpublished data, National Bureau of Standards, Washington, DC, prepared at request of Director, WES, Vicksburg, MS, by letter of 2 May 1950.

4 Tests and Results

The Tests

Initial test series

Initially, wave heights and wave patterns were obtained for existing conditions (Plate 1) and 21 test plan variations in the design elements of four basic improvement plan concepts. Basic improvement plans consisted of an offshore breakwater with the entrance oriented to the west, a dogleg breakwater with the entrance oriented to the east, and rubble absorbers and/or spurs installed along the insides of the existing jetties. Wave heights and wave patterns were obtained for initial test wave conditions from 34 deg. Brief descriptions of the initial test plans are presented in the following subparagraphs; dimensional details are presented in Plates 2-15. Typical structure cross sections for initial tests are shown in Plate 16.

a. Plan Concept 1: East Jetty Detached Breakwater.

(1) Plan 1 (Plate 2) consisted of a 389-m-long (1,275-ft-long) offshore breakwater with an entrance opening oriented toward the west. The structure had a 3.7-m (12-ft) crest width, a crest el of +3.4 m (+11 ft), and 3,266- to 7,257-kg (3.6- to 8.0-ton) armor stone installed on 1V:2H slopes.

(2) Plan 1A (Plate 2) involved the offshore breakwater of Plan 1 with a 38-m-long (125-ft-long) extension of the west jetty. This configuration left a 183-m-wide (600-ft-wide) entrance opening. The jetty extension had the same cross section as the offshore breakwater except the crest el was +2.3 m (+7.5 ft).

(3) Plan 1B (Plate 3) included the offshore breakwater and the west jetty extension of Plan 1A with a 91.4-m-long (300-ft-long) rubble absorber along the inside of the east jetty at its outer end. The absorber had a crest el of +2.3 m (+7.5 ft) and a crest width of 2.4 m (8.0 ft) with 3,266- to 7,257-kg (3.6- to 8.0-ton) armor stone installed on a 1V:2H slope.

(4) Plan 1C (Plate 3) entailed the offshore breakwater, west jetty extension, and east jetty absorber of Plan 1B, but the breakwater was extended lakeward 71.6 m (235 ft) resulting in a 460-m-long (1,510-ft-long) structure.

b. Plan Concept 2: West Jetty Dogleg Extension.

(1) Plan 2 (Plate 4) consisted of a 280-m-long (920-ft-long) dogleg breakwater extending lakeward from the west jetty and oriented to form an entrance opening toward the east. The plan also included a 213-m-long (700-ft-long) rubble absorber along the inside of the west jetty at its outer end. Both the breakwater and absorber had 3,266- to 7,257-kg (3.6- to 8.0-ton) armor stone installed on 1V:2H slopes. The crest el of the breakwater was +3.4 m (+11 ft) and the crest el of the absorber was +2.3 m (+7.5 ft). Crest widths were 3.7 and 2.4 m (12 and 8 ft) for the breakwater and absorber, respectively.

(2) Plan 2A (Plate 5) included the dogleg breakwater and west jetty absorber of Plan 2, but the breakwater was extended lakeward 88.4 m (290 ft) resulting in a 369-m-long (1,210-ft-long) structure. The extension involved that portion of the structure on the alignment of the west jetty and not the arm.

c. Plan Concept 3: Rubble-mound Wave Absorbers.

(1) Plan 3 (Plate 6) consisted of 411-m-long (1,350-ft-long) rubble absorbers along the insides of both the existing east and west jetties. They were constructed with 3,266- to 7,257-kg (3.6- to 8.0-ton) armor stone placed on 1V:2:H slopes. The crests were 2.4 m (8 ft) in width with els of +2.3 m (+7.5 ft).

(2) Plan 3A (Plate 7) entailed rubble absorbers along the insides of the existing jetties similar to Plan 3, but the west absorber was 966 m (3,170 ft) in length and the east absorber was 767 m (2,515 ft) long.

(3) Plan 3B (Plate 8) included the rubble absorbers along the insides of the existing jetties similar to Plan 3, but they were positioned along the shoreward ends of the structures. The west absorber was 411 m (1,350 ft) in length and the east absorber was 320 m (1,050 ft) long.

(4) Plan 3C (Plate 8) consisted of the elements of Plan 3B with the addition of two rubble-mound spurs at the shoreward ends of the absorbers. The spurs were 24.4 m (80 ft) long and were constructed with 3,266- to 7,257-kg (3.6- to 8.0-ton) armor stone placed on 1V:2H slopes (except at their heads, where the slope steepened to prevent encroachment into the navigation

channel). The crests of the spurs were 3.7 m (12 ft) wide with els of +2.3 m (+7.5 ft).

(5) Plan 3D (Plate 9) involved a 411-m-long (1,350-ft-long) west absorber and a 320-m-long (1,050-ft-long) east absorber situated along the inside of the existing jetties at their lakeward ends.

(6) Plan 3E (Plate 9) included the elements of Plan 3D with two 24.4-m-long (80-ft-long) rubble-mound spurs installed at the shoreward ends of the absorbers.

(7) Plan 3F (Plate 10) consisted of the 411-m-long (1,350-ft-long) rubble absorber linings of Plan 3 installed along the insides of the existing jetties with three pairs of 24.4-m-long (80-ft-long) spurs. The center line of the outer set of spurs was 152 m (500 ft) shoreward of the head of the existing west jetty, and the center lines of the middle and inner pair of spurs were 396 and 640 m (1,300 and 2,100 ft), respectively, shoreward of the head of the existing west jetty.

(8) Plan 3G (Plate 11) entailed a 747-m-long (2,450-ft-long) west absorber and a 649-m-long (2,130-ft-long) east absorber along the insides of the existing jetties. Both originated at the lakeward ends of the jetties and extended shoreward.

(9) Plan 3H (Plate 11) included the absorbers of Plan 3G with two 24.4-m-long (80-ft-long) spurs located toward the lakeward ends of the absorbers.

(10) Plan 3I (Plate 12) involved the 411-m-long (1,350-ft-long) rubble absorbers of Plan 3 installed along the insides of the existing jetties with two pairs of 24.4-m-long (80-ft-long) spurs.

(11) Plan 3J (Plate 13) consisted of eleven 30.5-m-long (100-ft-long) segmented absorbers installed along the inside of the west jetty and nine 30.5-m-long (100-ft-long) segmented absorber sections installed along the inside of the east jetty. Distance between the segments along the crests was 30.5 m (100 ft).

(12) Plan 3K (Plate 13) entailed the segmented absorbers of Plan 3J with a 61-m-long (200-ft-long) rubble absorber installed adjacent to the vertical Yacht Club dock inside the river south of the existing jetties. The absorber included 3,266- to 7,257-kg (3.6- to 8.0-ton) armor stone installed on a 1V:2H slope. The crest el of the absorber was +2.3 m (+7.5 ft) and its width was 2.4 m (8.0 ft).

d. Plan Concept 4: Spurs.

(1) Plan 4 (Plate 14) consisted of three pairs of 24.4-m-long (80-ft-long) rubble-mound spurs installed between the existing jetties. The center line of the outer pair of spurs was 152 m (500 ft) shoreward of the head of the existing west jetty, and the center lines of the middle and inner pair of spurs were 396 and 640 m (1,300 and 2,100 ft), respectively, shoreward of the head of the existing west jetty.

(2) Plan 4A (Plate 14) entailed the elements of Plan 4, but the outer pair of spurs was removed from between the jetties, resulting in a plan with two pairs of 24.4-m-long (80-ft-long) spurs.

(3) Plan 4B (Plate 15) included the middle and inner pairs of spurs of Plan 4 with an additional pair of 24.4-m-long (80-ft-long) spurs installed at the inner end of the east jetty.

Refined test series

After evaluation of initial test results and existing harbor conditions, the more cost-effective improvement plan concepts were subjected to refined wave conditions (as determined in a sensitivity analysis (conducted by the Buffalo District) of wave conditions and recurrence intervals). Stone sizes used for the improvement plans also were refined (reduced in size) based on initial wave heights obtained in the entrance channel. Tests were conducted for existing conditions and 19 design alternatives of rubble-mound absorbers and/or spurs installed along the insides of the existing jetties. Brief descriptions of the test plans are presented in the following subparagraphs; dimensional details are presented in Plates 17-27. Typical structure cross sections are shown in Plate 28.

a. Plan 3L (Plate 17) consisted of a 411-m-long (1,350-ft-long) west rubble absorber and a 320-m-long (1,050-ft-long) east rubble absorber placed along the insides of the existing jetties at their shoreward ends. The absorbers included 1,542- to 3,402-kg (3,400- to 7,500-lb) armor stone placed on 1V:2H slopes. The crests were 2 m (6.5 ft) wide with els of +2.3 m (+7.5 ft). The lakeward 61-m-long (200-ft-long) portions of both absorbers included additional toe protection (see cross sections, Plate 28). The shoreward 168 m (550 ft) of the west absorber and 76 m (250 ft) of the east absorber included an environmental feature, which consisted of a 3-m- (10-ft-) thick layer of a 50-percent mixture of pea gravel and 0.5- to 18-kg (1- to 40-lb) stone placed on slopes of 1V:2H from the -1.5-m (-6-ft) el to the existing bottom (see Plate 28).

b. Plan 3M (Plate 17) entailed the elements of Plan 3L, but 30 m (100 ft) was removed from the lakeward ends of each absorber

resulting in a 381-m-long (1,250-ft-long) west absorber and a 290-m-long (950-ft-long) east absorber.

c. Plan 3N (Plate 17) included the elements of Plan 3L, but 61 m (200 ft) was removed from the lakeward ends of each absorber resulting in a 350-m-long (1,150-ft-long) west absorber and a 259-m-long (850-ft-long) east absorber.

d. Plan 3O (Plate 17) involved the elements of Plan 3L, but 91 m (300 ft) was removed from the lakeward ends of each absorber resulting in a 320-m-long (1,050-ft-long) west absorber and a 229-m-long (750-ft-long) east absorber.

e. Plan 3P (Plate 17) entailed the elements of Plan 3L, but 122 m (400 ft) was removed from the lakeward ends of each absorber resulting in a 289-m-long (950-ft-long) west absorber and a 198-m-long (650-ft-long) east absorber.

f. Plan 3Q (Plate 17) involved the elements of Plan 3L, but 152 m (500 ft) was removed from the lakeward ends of each absorber resulting in a 259-m-long (850-ft-long) west absorber and a 168-m-long (550-ft-long) east absorber.

g. Plan 3R (Plate 17) included the elements of Plan 3L, but 183 m (600 ft) was removed from the lakeward ends of each absorber resulting in a 228-m-long (750-ft-long) west absorber and a 137-m-long (450-ft-long) east absorber.

h. Plan 3S (Plate 18) consisted of the 411-m-long (1,350-ft-long) west absorber and 320-m-long (1,050-ft-long) east absorber of Plan 3L with a 61-m-long (200-ft-long) absorber placed along the yacht club wall upstream of the jetties. The cross section of the yacht club dock absorber was the same as the rubble absorbers along the trunks of the existing jetties.

i. Plan 3T (Plate 19) entailed the 411-m-long (1,350-ft-long) west absorber and the 320-m-long (1,050-ft-long) east absorber linings of Plan 3L with the addition of two rubble-mound spurs. The spurs were 16.8 m (55 ft) long and included 1,542 to 3,402 kg (3,400 to 7,500 lb) armor stone placed on 1V:2H slopes. The crests of the spurs were 3 m (10 ft) wide with els of +2.3 m (+7.5 ft).

j. Plan 3U (Plate 19) involved the west and east absorber linings and spurs of Plan 3T with a 61-m-long (200-ft-long) absorber placed along the yacht club wall.

k. Plan 3V (Plate 20) consisted of a 503-m-long (1,650-ft-long) west rubble absorber and a 411-m-long (1,350-ft-long) east rubble absorber placed along the inside of the existing jetties at their shoreward ends.

l. Plan 3W (Plate 20) included the west and east absorber linings of Plan 3V with a 61-m-long (200-ft-long) absorber placed along the yacht club wall.

m. Plan 3X (Plate 21) consisted of five 46-m-long (150-ft-long) segmented absorber sections installed along the insides of the west and east jetties. Distances between the segments were 46 m (150 ft) along the crests. The outer two absorber segments (head segments) on each jetty included additional armor toe protection (see cross sections, Plate 28). The plan also included a 168-m (550-ft) west absorber and a 76-m (250-ft) east absorber with an environmental feature at the shoreward ends of the existing jetties.

n. Plan 3Y (Plate 22) involved the elements of Plan 3X with four segmented absorber sections (two head sections and two trunk sections) placed along the insides of each jetty as well as the absorber sections with the environmental feature.

o. Plan 3Z (Plate 22) entailed the elements of Plan 3Y with a 61-m-long (200-ft-long) absorber placed along the yacht club wall upstream of the jetties.

p. Plan 3AA (Plate 23) included the elements of Plan 3X with three segmented absorber sections (two head sections and one trunk section) placed along the insides of each jetty as well as the absorber sections with the environmental feature.

q. Plan 3BB (Plate 23) involved the elements of Plan 3AA with a 61-m-long (200-ft-long) absorber placed along the yacht club wall.

r. Plan 3CC (Plate 24) entailed the elements of Plan 3X with two segmented absorber sections (two head sections) placed along the insides of each jetty as well as the absorber sections with the environmental feature.

s. Plan 3DD (Plate 24) included the elements of Plan 3CC with a 61-m-long (200-ft-long) absorber placed along the yacht club wall.

t. Plan 4C (Plate 25) consisted of three pairs of 16.8-m-long (55-ft-long) rubble-mound spurs installed between the existing jetties. The outer pair of spurs originated 183 m (600 ft) shoreward of the head of the existing east jetty, and the middle and inner set of spurs originated 427 and 671 m (1,400 and 2,200 ft) shoreward of the head of the west jetty. The spurs included 1,542- to 3,402-kg (3,400- to 7,500-lb) armor stone placed on 1V:2H slopes. Their crests were 3 m (10 ft) wide with els of +2.3 m (+7.5 ft).

u. Plan 4D (Plate 26) involved the two outer pairs of spurs of Plan 4C. The inner set of spurs were removed.

v. Plan 4E (Plate 26) included the two pairs of spurs of Plan 4D with a 61-m-long (200-ft-long) absorber placed along the yacht club wall.

w. Plan 4F (Plate 27) entailed only the inner set of spurs of Plan 4C. The outer two pairs of spurs were removed.

Wave height tests and wave patterns

Wave heights and wave patterns were obtained for existing conditions and the various improvement plans for test waves from one or more of the directions listed on pages 21 and 22. Tests involving certain proposed plans were limited to the most critical direction of wave approach (i.e., 34 or 49 deg). Plans not meeting the 0.3-m (1.0-ft) criterion were eliminated from further consideration. Several alternatives meeting the criterion were also eliminated because more cost-effective alternatives were identified. Project alternatives were screened by the length of rubble-mound absorber and/or the number of spurs. Existing conditions and the optimum improvement plan (Plan 3BB) were tested comprehensively for waves from all directions. Wave gauge locations are shown in the referenced plates.

River current velocity, water-surface elevation, and riverine sediment tracer tests

River current velocity measurements, water-surface profiles, and riverine sediment tracer tests were conducted for existing conditions and the optimum improvement plan (Plan 3BB). These measurements were secured at various locations in the lower reaches of the river for 2-, 10-, and 100-year discharges using the +0.76-m (+2.5-ft) swl with no wave conditions. Stations originated at the entrance (even with the outer end of the west jetty) and extended upstream along the center line of the maintained channels.

River plume and surface currents

Tests of river plume and surface currents (generated by river discharge) were conducted for existing conditions and the optimum improvement plan (Plan 3BB). Plume tests were conducted with two river flow conditions, and surface current tests were conducted for one river flow condition for waves from the three test directions with the +0.76-m (+2.5-ft) swl. Movement of the plume as the river water entered the lake was defined and tracked by injecting dye in the river. Small pieces of styrofoam confetti were used to track river surface currents through the jetties and into the lake.

Test Results

In analyzing test results, the relative merits of various improvement plans were based initially on measured wave heights in the harbor mooring areas and lower reaches of the river. Further evaluation of the selected plan was based on the movement of riverine sediment tracer material and subsequent deposits, water-surface elevations, river current patterns and velocities, and visual observations. Model wave heights (significant wave heights or H_s), water-surface elevations, and river current velocities were tabulated to show measured values at selected locations. Riverine sediment tracer patterns, river plume, surface currents, and wave patterns were photographed. Arrows have been superimposed onto these photographs, in some cases, to define direction of movement.

Initial test series

Wave heights obtained for existing conditions are presented in Table 1 for initial test waves from 34 deg. For the swl of +0.76 m (+2.5 ft), maximum wave heights were 1.07 m (3.5 ft) in the lower reaches of the river south of the existing jetties (Gauges 1-11) for 20-year navigation season wave conditions. For the +1.43-m (+4.7-ft) swl, maximum wave heights in the lower reaches of the river were 1.22 m (4.0 ft) for 20-year all-season waves. Typical wave patterns for existing conditions are shown in Photo 1.

Results of wave height tests for Plans 1-1C are presented in Tables 2-5 for initial test waves from 34 deg. Maximum wave heights were 0.52, 0.43, 0.34, and 0.24 m (1.7, 1.4, 1.1, and 0.8 ft), respectively, for Plans 1-1C in the lower reaches of the river for 20-year navigation season wave conditions with the +0.76-m (+2.5-ft) swl. For the +1.43-m (+4.7-ft) swl, maximum wave heights were 0.70, 0.58, 0.49, and 0.37 m (2.3, 1.9, 1.6, and 1.2 ft) for Plans 1-1C, respectively, in the lower reaches of the river for 20-year all-season waves. Typical wave patterns for Plans 1-1C are shown in Photos 2-5.

Wave height test results for Plans 2 and 2A are presented in Tables 6 and 7 for initial test waves from 34 deg. For the +0.76-m (+2.5-ft) swl, maximum wave heights were 0.24 and 0.27 m (0.8 and 0.9 ft), respectively, for Plans 2 and 2A in the lower reaches of the river for 20-year navigation season wave conditions. With the +1.43-m (+4.7-ft) swl, maximum wave heights were 0.40 and 0.43 m (1.3 and 1.4 ft) in the lower reaches of the river for Plans 2 and 2A, respectively, for 20-year all-season waves. Typical wave patterns for Plans 2 and 2A are shown in Photos 6 and 7.

Wave heights obtained for Plans 3- 3K for initial test waves from 34 deg are presented in Tables 8-19. For the +0.76-m (+2.5-ft) swl, maximum wave heights in the lower reaches of the river were 0.40, 0.27, 0.46, 0.37, 0.70, 0.70, 0.30, 0.46, 0.40, 0.37, 0.37, and 0.37 m (1.3, 0.9, 1.5, 1.2, 2.3, 2.3, 1.0, 1.5, 1.3, 1.2, 1.2, and 1.2 ft) for Plans 3-3K, respectively, for 20-year

navigation season wave conditions. With the +1.43-m (+4.7-ft) swl, maximum wave heights were 0.58, 0.40, 0.58, 0.49, 0.79, 0.76, 0.34, 0.64, 0.55, 0.43, 0.46, and 0.46 m (1.9, 1.3, 1.9, 1.6, 2.6, 2.5, 1.1, 2.1, 1.8, 1.4, 1.5, and 1.5 ft) in the lower reaches of the river for 20-year all-season waves for Plans 3-3K, respectively. Typical wave patterns for Plans 3-3K are shown in Photos 8-19.

Results of wave height tests for Plans 4-4B are presented in Tables 20-22 for initial test waves from 34 deg. Maximum wave heights with the +0.76-m (+2.5-ft) swl were 0.40, 0.40, and 0.37 m (1.3, 1.3, and 1.2 ft) for 20-year navigation season wave conditions for Plans 4-4B, respectively. For the +1.43-m (+4.7-ft) swl, maximum wave heights were 0.46, 0.46, and 0.40 m (1.5, 1.5, and 1.3 ft) for Plans 4-4B, respectively, with 20-year all-season waves. Typical wave patterns for Plans 4-4B are shown in Photos 20-22.

Refined test series

Wave height test results for existing conditions are presented in Table 23 for refined test waves from 49, 34, and 354 deg. For the +0.76-m (+2.5-ft) swl, maximum wave heights in the lower reaches of the river were 1.01, 0.82, and 0.98 m (3.3, 2.7, and 3.2 ft), respectively, for 20-year navigation season test waves from 49, 34, and 354 deg. With the +1.43-m (+4.7-ft) swl, maximum wave heights were 1.07, 1.01, and 0.94 m (3.5, 3.3, and 3.1 ft) for 20-year all-season waves in the lower reaches of the river for test waves from 49, 34, and 354 deg, respectively. Representative wave patterns for existing conditions are shown in Photos 23-31.

Results of refined wave height tests for Plans 3L-3R for 5.8-sec, 7.2-ft test waves (20-year navigation season waves) from 34 deg with the +0.76-m (+2.5-ft) swl are presented in Table 24. Maximum wave heights in the lower reaches of the river at gauges 1-11 were 0.27, 0.27, 0.30, 0.30, 0.27, 0.34, and 0.34 m (0.9, 0.9, 1.0, 1.0, 0.9, 1.1, and 1.1 ft) for Plans 3L-3R, respectively. Typical wave patterns obtained for Plans 3L-3R are shown in Photos 32-38.

Wave heights obtained for Plans 4C-4F for 5.8-sec, 7.2-ft refined test waves (20-year navigation season waves) from 34 deg with the +0.76-m (+2.5-ft) swl are presented in Table 25. Maximum wave heights were 0.24, 0.46, 0.52, and 0.52 m (0.8, 1.5, 1.7, an 1.7 ft) for Plans 4C-4F, respectively, in the lower reaches of the river at gauges 1-11. Typical wave patterns are shown in Photos 39-42 for Plans 4C-4F.

Refined wave height test results for Plans 3L, 3O, 3R-3DD, and 4C are presented in Table 26 for 6.4-sec, 9.1-ft test waves (20-year navigation season waves) from 49 deg with the +0.76-m (+2.5-ft) swl. Maximum wave heights were 0.40, 0.46, 0.52, 0.37, 0.37, 0.34, 0.34, 0.34, 0.30, 0.34, 0.27, 0.37, 0.27, 0.43, 0.37, and 0.70 m (1.3, 1.5, 1.7, 1.2, 1.2, 1.1, 1.1, 1.1, 1.0, 1.1, 0.9, 1.2, 0.9, 1.4, 1.2, and 2.3 ft) in the lower reaches of

the river at gauges 1-11 for Plans 3L, 3O, 3R-3DD, and 4C, respectively. Typical wave patterns for these plans are shown in Photos 43-58.

Refined wave heights obtained for Plan 3BB are presented in Table 27 for refined test waves from 49, 34, and 354 deg. For the +0.76-m (+2.5-ft) swl, maximum wave heights were 0.27, 0.18, and 0.24 m (0.9, 0.6, and 0.8 ft) in the lower reaches of the river at gauges 1-11 for test waves from 49, 34, and 354 deg, respectively, for 20-year navigation season wave conditions. With the +1.43-m (+4.7-ft) swl, maximum wave heights in the lower reaches of the river were 0.40, 0.36, and 0.30 m (1.3, 1.1, and 1.0 ft) for test waves from 49, 34, and 354 deg, respectively, for 20-year all-season waves. Typical wave patterns for Plan 3BB are shown in Photos 59-67.

Water-surface elevations (el) and depth-averaged river velocities obtained in the lower reaches of the Genesee River for existing conditions and Plan 3BB are presented in Table 28 for 2-, 10-, and 100-year discharges. For existing conditions, the maximum rise in water surface elevation in the river ranged from 0.03 m (0.1 ft) for the 2-year discharge to 0.09 m (0.3 ft) for the 100-year discharge; and maximum velocities in the river ranged from 1.22 m/s (4.0 ft/s) to 2.23 m/s (7.3 ft/s) for the 2- and 100-year discharges. With Plan 3BB installed, maximum water surface elevations rose from 0.03 (0.1 ft) for the 2-year discharge to 0.12 m (0.4 ft) for the 100-year discharge; and maximum velocities in the river ranged from 1.16 m/s (3.8 ft/s) to 2.04 m/s (6.7 ft/s) for the 2- and 100-year discharges.

Riverine sediment tracer movement is illustrated in Photos 68 and 69 for existing conditions and Plan 3BB, respectively. Sediment did not move for the 2- and 10-year river discharges for either existing conditions or Plan 3BB, and only minor movement occurred for the 100-year discharge. River discharges were increased to some value with greater than a 100-year recurrence (1,192-cms, 42,100-cfs) to determine movement patterns. Note that the sediment movement patterns for existing conditions and Plan 3BB were similar, with downstream movement directly down the axis of the channel for the larger flows.

Movement of the plume as river water moved downstream between the jetties and entered the lake is shown in Photos 70-72 and 73-75 for existing conditions and Plan 3BB, respectively, for various river discharges and wave directions. In general, plume movement was toward the east for test waves from 354 deg and toward the west for test waves from 49 deg for both existing conditions and Plan 3BB. For test waves from 34 deg, the plume tended to move straight out into the lake for both existing conditions and Plan 3BB.

The progression of confetti movement during river surface-current tests is shown in Photos 76-78 for existing conditions and Photos 79-81 for Plan 3BB for various river discharges and wave directions. The confetti moved downstream and as it entered the lake, in general, movement was toward the east for waves from 354 deg, toward the west for waves from 49 deg, and straight into the lake for waves from 34 deg for both

existing conditions and Plan 3BB. The rubble absorber linings of Plan 3BB did not interfere with the passage of the floating debris, and no potential jamming of the river was observed.

Discussion of Test Results

Initial test series

Results of wave height tests for existing conditions for initial test waves revealed rough and turbulent wave conditions in the lower reaches of the river. Wave heights in excess of 0.9 m (3.0 ft) were measured for 20-year wave conditions during recreational boating season (swl = +0.76 m (+2.5 ft)). Visual observations also revealed very confused wave patterns in the lower reaches of the river due to reflections from the vertical walls lining the river and basins.

Wave height tests obtained for the east jetty detached breakwater configurations with the entrance opening oriented toward the west (Plans 1-1C) indicated, for initial test waves, that Plan 1C would meet the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river for 20-year wave conditions during recreational boating season. Plan 1B resulted in wave heights that exceeded the criterion by only 0.03 m (0.1 ft) at one gauge location for the 20-year boating season conditions.

Results of wave height tests for initial test waves with the dogleg breakwater configurations oriented to form an entrance opening to the east (Plans 2 and 2A) indicated that both test plans would meet the established 0.3-m (1.0-ft) criterion in the lower reaches of the river for 20-year wave conditions occurring during the recreational boating season.

Wave heights obtained for the rubble absorber linings, both with and without spurs, along the insides of the existing jetties (Plans 3-3K) revealed that Plans 3A and 3F would meet the established 0.3-m (1.0-ft) criterion in the lower reaches of the river for 20-year boating season conditions with initial test waves. Several additional plans (Plans 3C, 3I, 3J, and 3K) exceeded the criterion by only 0.03 to 0.06 m (0.1 to 0.2 ft) in the lower reaches of the river for boating season wave conditions with a 20-year recurrence interval.

Results of wave height tests with spurs only installed along the insides of the existing jetties (Plans 4-4B) for initial test waves indicated that none of the plans would meet the desired 0.3-m (1.0-ft) criterion for 20-year navigation season waves. Plan 4B exceeded the criterion by only 0.06 m (0.1 ft), however, for the 20-year recreational navigation season waves.

At this point in the model investigation, test conditions were reevaluated. Initial test waves selected for testing in the model by the Buffalo

District were developed considering a 60-deg arc approach angle. From this 60-deg angle of approach, the most severe wave conditions were selected and generated directly up the axis of the channel (i.e., 34 deg) in the model to determine the effectiveness of the various plan concepts. After evaluation of the initial test plans, a sensitivity analysis of wave conditions by direction and recurrence interval was conducted by the Buffalo District. It was determined that the most severe wave conditions did not approach directly up the axis of the channel, but approximately 15 deg easterly of this alignment (i.e., 49 deg). As a result of this analysis, refined test wave conditions were selected and generated throughout the remainder of the model investigation.

An economic analysis of the improvement plan alternatives, at this point, revealed that the offshore and dogleg breakwater configurations were not considered cost effective. Since the more cost-effective plans entailed rubble structures installed along the insides of the existing jetties, armor stone sizes were adjusted (refined) based on wave heights obtained between the jetties for initial test conditions. This resulted in reduced stone sizes for the absorbers proposed between the jetties, since initial stone sizes were based on structures (and corresponding wave environment) installed lakeward of the existing jetties.

Refined test series

Results of wave height tests for existing conditions for refined test waves revealed rough and turbulent wave conditions in the lower reaches of the river with wave heights in excess of 0.9 m (3 ft) during recreational boating season for 20-year wave conditions. Observations also revealed very confused wave patterns due to reflections from the vertical walls lining the lower reaches of the river and the boat basins.

Wave height tests obtained for Plans 3L-3R for 20-year refined wave conditions from 34 deg occurring during the navigation season indicated that several of the improvement plans (Plans 3L-3P) met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river. Plans 3Q and 3R exceeded the criterion by only 0.03 m (0.1 ft) at one gauge location in the river for these conditions. Wave height test results for Plans 4C-4F for refined boating season waves from 34 deg revealed that only Plan 4C met the established criterion in the lower reaches of the river for 20-year wave conditions.

Results of wave heights for Plans 3L, 3O, 3R-3DD, and 4C for refined 20-year boating season waves from 49 deg revealed that several plans (Plans 3X, 3Z, and 3BB) met the established 0.03-m (1.0-ft) criterion in the lower reaches of the river at gauges 1-11. Several additional plans (Plans 3S, 3T, 3U, 3V, 3W, 3Y, 3AA, and 3DD) exceeded the criterion by only 0.03 to 0.06 m (0.1 to 0.2 ft) in the lower reaches of the river. Evaluation by the Buffalo District of wave conditions in the lower reaches of the river versus projected construction costs of the various improvement

plans revealed that Plan 3BB was optimum. Therefore, Plan 3BB was re-installed in the model and subjected to comprehensive testing.

Results of wave height tests for refined test waves for all directions for Plan 3BB revealed that maximum wave heights would not exceed 0.27 m (0.9 ft) in the lower reaches of the river for recreational boating wave conditions with a 20-year recurrence interval. Plan 3BB also will result in less confused wave patterns in the river south of the existing jetties than existing conditions, as shown in Photo 82.

Water-surface profiles obtained for existing conditions and Plan 3BB indicated that the improvement plan will not result in significant rises in water surface elevation in the river for discharges up to a 100-year recurrence interval. Maximum elevations were exactly the same for 2- and 10-year recurrence intervals for existing conditions and Plan 3BB; and only varied 0.03 m (0.1 ft) for the 100-year discharge. River current velocities obtained for existing conditions and Plan 3BB were also similar, with variations of only 0.06, 0.06, and 0.18 m/s (0.2, 0.2, and 0.6 ft/s) in the maximum discharges for the 2-, 10-, and 100-year flows. The rubble absorber linings of Plan 3BB should have no negative impacts on water surface elevations and river velocities.

Riverine sediment tracer tests for existing conditions and Plan 3BB suggested very little bed-load sediment movement will occur for river discharges up to a 100-year recurrence. Discharges with greater than a 100-year recurrence resulted in similar patterns for both existing conditions and Plan 3BB. Sediment moved downstream with no shoaling tendencies caused by the rubble-mound absorbers.

River plume tests and river surface-currents obtained for existing conditions and Plan 3BB revealed similar patterns as the river currents propagated through the jetties and entered the lake. The rubble-mound absorbers along the insides of the existing jetties (Plan 3BB) did not alter the current patterns or interfere with river flows, and no tendency for surface material to hang up or jam along the structure was observed.

5 Conclusions

Based on the results of the coastal hydraulic model investigation reported herein, it is concluded that:

a. Existing conditions are characterized by rough and turbulent wave conditions during periods of storm wave attack, aggravated by reflections off the vertical wall linings in the lower reaches of the river. Wave heights in excess of 0.9 m (3.0 ft) occurred in the lower reaches of the river during boating season for both initial and refined test conditions.

b. Of the improvement plans which included an offshore breakwater with the entrance oriented to the west, Plan 1C (Plate 3) met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the navigation season for initial test conditions.

c. Both the improvement plans which entailed a dogleg breakwater and entrance orientation to the east (Plans 2 and 2A, Plates 4 and 5) met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the navigation season for initial test conditions.

d. Of the improvement plans which consisted of rubble-mound absorbers and/or spurs along the insides of the existing jetties, Plans 3A and 3F (Plates 7 and 10) met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the navigation season for initial test conditions.

e. Based on results of initial test conditions, it was determined that the more cost-effective alternatives would consist of some combination of rubble absorbers and/or spurs installed along the insides of the existing jetties.

f. Of the improvement plans which included rubble-mound absorbers, both with and without spurs, along the insides of the existing jetties, Plans 3X, 3Z, and 3BB (Plates 21, 22, and 23) met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the recreation season for refined test conditions.

g. Of the improvement plans which entailed only spurs along the insides of the existing jetties, none met the established wave height criterion in the lower reaches of the river for refined test conditions.

h. Based on results of refined test conditions, the segmented absorber configuration of Plan 3BB was selected as optimum considering both wave protection provided and costs.

i. Construction of the rubble-mound absorbers between the jetties (Plan 3BB) will have minimal impact on water-surface elevations and river current velocities for the various river discharges.

j. Construction of the rubble-mound absorbers (Plan 3BB) will not alter riverine bed-load sediment movement patterns between the existing jetties.

k. Construction of the rubble-mound absorbers (Plan 3BB) will not alter the movement of the river plume or river surface-currents between the existing jetties or as the flow enters the lake.

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Table 1
Wave Heights for Existing Conditions; Initial Test Waves from 34 Degrees

	Test Wave		Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.6	0.2	0.3	1.4	0.6	0.7	2.6	0.3	0.3	1.7	1.5	2.1	2.6	2.7	4.1	5.0
5	5.8	7.1	0.8	0.4	0.5	1.7	1.0	1.3	2.7	0.8	1.0	2.7	2.5	3.2	4.0	3.0	5.5	6.5
20	6.4	9.1	1.0	0.7	0.8	2.2	1.7	1.9	3.2	1.5	1.9	3.3	3.5	4.2	4.8	4.0	6.8	7.5
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.3	0.3	0.3	1.4	1.1	1.5	2.5	0.7	0.8	2.5	2.6	2.6	3.2	2.7	5.0	6.1
5	6.3	8.4	0.6	0.5	0.6	1.9	1.6	1.9	3.1	1.2	1.7	2.7	3.5	3.5	4.2	3.4	6.9	7.3
20	6.7	10.0	0.7	0.8	0.8	2.1	2.0	2.2	3.2	1.6	2.0	3.2	4.0	4.0	4.2	4.6	7.7	8.9

[1] RI = Recurrence interval, years

Table 2
Wave Heights for Plan 1; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.1	0.5	0.2	0.1	1.0	0.1	0.2	0.5	0.5	0.7	0.8	0.8	1.5	2.8
5	5.8	7.1	0.3	0.2	0.2	0.8	0.5	0.5	1.5	0.5	0.6	1.2	1.1	1.4	1.5	1.4	2.3	4.5
20	6.4	9.1	0.5	0.4	0.5	0.9	0.9	0.9	1.6	0.8	0.9	1.5	1.7	1.6	1.9	1.6	2.3	5.0
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.2	0.7	0.7	0.7	1.1	0.5	0.5	1.2	1.2	1.2	1.3	1.2	2.0	3.8
5	6.3	8.4	0.4	0.3	0.3	0.9	1.1	1.1	1.6	0.8	1.0	1.6	1.7	1.6	1.8	1.6	2.4	4.9
20	6.7	10.0	0.5	0.5	0.5	1.1	1.4	1.5	2.0	1.2	1.5	1.8	2.3	2.0	2.2	2.0	2.8	5.6

[1] RI = Recurrence interval, years

Table 3
Wave Heights for Plan 1A; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.1	0.4	0.1	0.1	0.8	0.1	0.1	0.6	0.2	0.8	0.8	0.9	1.6	2.9
5	5.8	7.1	0.3	0.1	0.2	0.5	0.4	0.4	1.0	0.4	0.5	1.1	0.7	1.1	1.2	1.4	1.9	3.7
20	6.4	9.1	0.5	0.1	0.5	0.9	0.8	0.8	1.4	0.7	0.8	1.4	1.2	1.5	1.6	1.7	2.4	4.9
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.3	0.3	0.2	0.6	0.6	0.9	1.3	0.5	0.6	1.3	0.9	1.5	1.5	1.4	2.2	4.0
5	6.3	8.4	0.3	0.3	0.3	0.6	0.8	0.8	1.3	0.7	0.8	1.3	1.1	1.5	1.5	1.5	2.2	4.3
20	6.7	10.0	0.5	0.5	0.4	0.9	1.2	1.3	1.7	1.0	1.2	1.9	1.9	2.1	2.1	2.0	3.2	6.0

[1] RI = Recurrence interval, years

Table 4
Wave Heights for Plan 1B; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.1	0.4	0.2	0.2	0.5	0.2	0.2	0.6	0.4	0.7	0.6	0.6	1.4	2.6
5	5.8	7.1	0.2	0.1	0.2	0.4	0.4	0.3	0.9	0.4	0.5	0.8	0.6	0.7	0.8	0.6	1.9	3.7
20	6.4	9.1	0.4	0.1	0.5	0.5	0.7	0.6	1.1	0.7	0.7	1.0	0.9	0.8	0.9	0.8	2.1	4.4
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.2	0.5	0.4	0.6	0.7	0.4	0.5	0.8	0.8	0.9	1.0	0.8	2.1	3.6
5	6.3	8.4	0.3	0.3	0.3	0.7	0.7	0.8	0.9	0.6	0.7	0.9	1.1	1.0	1.1	0.9	2.4	4.3
20	6.7	10.0	0.4	0.5	0.5	0.9	1.1	1.2	1.2	1.1	1.2	1.2	1.6	1.2	1.3	1.2	2.8	5.3

[1] RI = Recurrence interval, years

Table 5
Wave Heights for Plan 1C; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.2	0.3	0.4	1.1	1.8
5	5.8	7.1	0.2	0.1	0.2	0.1	0.3	0.1	0.3	0.3	0.3	0.6	0.2	0.4	0.5	0.5	1.4	2.5
20	6.4	9.1	0.3	0.1	0.4	0.2	0.6	0.5	0.6	0.5	0.6	0.8	0.6	0.6	0.7	0.7	1.6	3.2
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.1	0.4	0.5	0.4	0.7	0.4	0.5	0.6	0.7	0.8	0.8	0.7	1.7	2.7
5	6.3	8.4	0.3	0.3	0.2	0.6	0.7	0.6	0.8	0.6	0.7	0.7	1.0	0.8	0.9	0.7	1.8	3.0
20	6.7	10.0	0.4	0.5	0.4	0.7	1.0	0.9	0.9	1.0	1.1	0.9	1.2	1.0	1.0	0.9	2.0	3.6

[1] RI = Recurrence interval, years

Table 6
Wave Heights for Plan 2; Initial Test Waves from 34 Degrees

	Test Wave		Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.1	0.2	0.3	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.4	0.4	0.4	1.3
5	5.8	7.1	0.3	0.2	0.4	0.3	0.5	0.4	0.5	0.4	0.4	0.5	0.4	0.6	0.7	0.6	0.8	1.9
20	6.4	9.1	0.4	0.3	0.7	0.4	0.8	0.6	0.7	0.6	0.6	0.8	0.6	0.9	1.0	1.0	1.2	2.8
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.3	0.3	0.3	0.3	0.7	0.3	0.4	0.4	0.4	0.7	0.7	0.7	0.7	2.0
5	6.3	8.4	0.3	0.3	0.4	0.4	0.7	0.5	0.9	0.6	0.6	0.7	0.6	0.9	1.0	0.9	1.2	2.5
20	6.7	10.0	0.5	0.4	0.7	0.7	0.9	0.9	1.3	0.8	0.9	1.0	0.9	1.3	1.3	1.3	1.8	3.5

[1] RI = Recurrence interval, years

Table 7
Wave Heights for Plan 2A; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.1	0.2	0.2	0.1	0.3	0.2	0.2	0.3	0.2	0.3	0.5	0.4	0.5	1.6
5	5.8	7.1	0.3	0.2	0.4	0.4	0.5	0.4	0.6	0.4	0.5	0.5	0.5	0.6	0.7	0.6	0.9	2.5
20	6.4	9.1	0.5	0.4	0.7	0.6	0.8	0.7	0.8	0.7	0.8	0.9	0.7	1.0	1.2	1.2	1.5	3.7
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.2	0.4	0.4	0.3	0.8	0.4	0.4	0.5	0.5	0.8	0.9	0.7	1.1	2.3
5	6.3	8.4	0.3	0.2	0.4	0.8	0.8	0.9	1.1	0.7	0.8	0.8	0.8	1.3	1.4	1.3	1.7	3.7
20	6.7	10.0	0.5	0.4	0.6	1.0	1.1	1.2	1.3	1.0	1.1	1.1	1.4	1.5	1.6	1.8	2.2	4.3

[1] RI = Recurrence interval, years

Table 8
Wave Heights for Plan 3; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.2	0.3	0.2	0.1	0.4	0.2	0.2	0.2	0.1	0.5	1.0	2.5	3.7	4.6
5	5.8	7.1	0.3	0.2	0.4	0.5	0.6	0.3	0.7	0.5	0.6	0.6	0.4	1.0	1.7	2.8	5.5	6.5
20	6.4	9.1	0.6	0.4	0.8	0.8	1.2	0.9	1.2	1.0	1.2	1.3	0.9	1.6	2.5	4.0	7.0	7.9
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.1	0.2	0.8	0.5	0.5	1.1	0.3	0.4	0.8	0.7	1.1	2.1	2.7	5.4	6.4
5	6.3	8.4	0.3	0.2	0.3	1.0	0.9	1.0	1.3	0.6	0.8	1.1	1.0	1.5	2.5	3.4	6.7	7.1
20	6.7	10.0	0.6	0.5	0.7	1.4	1.4	1.6	1.9	1.3	1.7	1.7	1.7	2.7	3.4	5.1	7.9	8.8

[1] RI = Recurrence interval, years

Table 9
Wave Heights for Plan 3A; Initial Test Waves from 34 Degrees

	Test Wave		Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.3	1.4	2.6	3.7	4.8
5	5.8	7.1	0.1	0.1	0.1	0.2	0.4	0.2	0.4	0.3	0.5	0.4	0.2	0.7	1.7	3.2	4.9	6.4
20	6.4	9.1	0.3	0.2	0.7	0.5	0.9	0.7	0.8	0.7	0.9	0.9	0.6	1.1	2.1	4.1	6.6	7.8
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.2	0.4	0.6	0.5	0.7	0.3	0.5	0.7	0.4	0.8	1.7	3.2	4.9	6.0
5	6.3	8.4	0.4	0.3	0.4	0.7	0.8	0.8	0.9	0.6	0.8	0.9	0.7	1.1	2.1	3.9	6.1	7.1
20	6.7	10.0	0.7	0.6	0.7	0.9	1.3	1.3	1.1	1.0	1.3	1.3	1.0	1.4	2.5	4.6	7.4	8.1

[1] RI = Recurrence interval, years

Table 10
Wave Heights for Plan 3B; Initial Test Waves from 34 Degrees

	Test Wave		Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.3	0.1	0.2	0.8	0.2	0.5	1.1	0.3	0.3	0.6	0.2	1.0	2.2	2.4	3.9	4.8
5	5.8	7.1	0.4	0.3	0.3	1.0	0.5	0.8	1.5	0.6	0.7	0.9	0.6	1.6	3.5	2.7	5.4	6.4
20	6.4	9.1	0.6	0.5	0.8	1.0	1.0	1.1	1.5	1.1	1.3	1.4	0.9	2.0	4.1	3.6	6.7	7.7
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.3	0.3	0.3	0.8	0.7	1.1	1.3	0.6	0.8	1.2	0.9	1.6	3.3	2.5	5.3	6.4
5	6.3	8.4	0.4	0.4	0.5	1.1	1.0	1.5	1.5	0.9	1.2	1.4	1.1	1.9	3.9	2.9	6.4	7.3
20	6.7	10.0	0.6	0.6	0.7	1.4	1.4	1.9	1.7	1.3	1.7	1.6	1.5	2.2	4.4	4.2	7.5	8.3

[1] RI = Recurrence interval, years

Table 11
Wave Heights for Plan 3C; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.1	0.6	0.2	0.5	0.8	0.3	0.3	0.5	0.1	1.1	2.4	2.4	4.1	4.9
5	5.8	7.1	0.3	0.2	0.3	0.7	0.5	0.7	1.0	0.5	0.6	0.7	0.4	1.5	3.2	2.9	5.4	6.2
20	6.4	9.1	0.6	0.5	0.8	0.8	1.1	1.1	1.2	1.0	1.1	1.2	0.8	1.9	4.1	3.6	6.8	7.5
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.3	0.3	0.2	0.8	0.6	0.9	1.1	0.4	0.7	1.0	0.7	1.7	3.3	2.6	5.1	6.2
5	6.3	8.4	0.4	0.4	0.4	0.9	0.9	1.2	1.2	0.8	1.0	1.1	1.0	1.9	3.9	3.0	6.4	7.3
20	6.7	10.0	0.6	0.6	0.7	1.1	1.4	1.6	1.4	1.3	1.6	1.4	1.4	2.3	4.6	4.5	7.8	8.8

[1] RI = Recurrence interval, years

Table 12
Wave Heights for Plan 3D; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.4	0.2	0.2	1.1	0.2	0.8	1.9	0.6	0.5	1.3	0.7	1.5	2.1	2.9	3.6	4.9
5	5.8	7.1	0.5	0.3	0.4	1.1	0.6	1.2	2.0	0.9	1.0	1.9	1.1	2.0	2.9	3.5	5.2	6.4
20	6.4	9.1	0.7	0.6	0.8	1.4	1.1	1.5	2.3	1.4	1.7	2.3	1.6	2.7	3.8	4.2	6.6	7.9
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.3	1.3	0.9	1.9	2.5	1.0	1.2	1.8	1.2	2.7	3.7	3.9	5.2	6.4
5	6.3	8.4	0.4	0.3	0.5	1.6	1.2	2.1	2.4	1.2	1.6	2.1	1.4	3.2	4.0	4.3	6.3	7.3
20	6.7	10.0	0.6	0.5	0.8	1.9	1.6	2.4	2.6	1.5	2.0	2.3	1.6	3.8	4.7	5.1	7.7	8.7

[1] RI = Recurrence interval, years

Table 13
Wave Heights for Plan 3E; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.5	0.3	0.2	1.1	0.3	1.1	1.9	0.5	0.5	1.3	0.7	1.9	1.7	3.1	4.0	5.0
5	5.8	7.1	0.6	0.3	0.4	1.1	0.6	1.3	2.1	0.8	1.0	1.9	1.0	2.1	2.5	3.8	5.2	6.7
20	6.4	9.1	0.7	0.6	0.8	1.4	1.1	1.7	2.3	1.4	1.6	2.3	1.6	2.6	3.5	4.5	6.9	7.9
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.4	0.4	0.3	1.3	0.9	2.0	2.2	1.1	1.1	1.9	1.1	2.4	3.0	3.7	5.0	6.1
5	6.3	8.4	0.5	0.5	0.5	1.5	1.2	2.2	2.4	1.3	1.5	2.0	1.4	3.1	3.8	4.4	6.4	7.2
20	6.7	10.0	0.7	0.6	0.7	1.9	1.6	2.5	2.5	1.5	2.0	2.3	1.6	3.5	4.3	5.0	7.7	8.5

[1] RI = Recurrence interval, years

Table 14
Wave Heights for Plan 3F; Initial Test Waves from 34 Degrees

	Test Wave		Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.6	0.9	2.6	4.1	5.0
5	5.8	7.1	0.1	0.1	0.2	0.1	0.3	0.2	0.2	0.2	0.5	0.4	0.2	0.7	1.1	3.3	5.5	6.5
20	6.4	9.1	0.3	0.1	0.7	0.5	1.0	0.6	0.6	0.6	0.8	0.8	0.6	0.9	1.3	3.7	6.8	7.6
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.3	0.3	0.2	0.5	0.4	0.5	0.6	0.4	0.4	0.5	0.5	0.8	1.3	3.4	5.3	6.3
5	6.3	8.4	0.4	0.3	0.4	0.6	0.8	0.7	0.7	0.7	0.6	0.6	0.6	1.0	1.4	4.0	6.6	7.2
20	6.7	10.0	0.4	0.5	0.8	0.6	1.1	0.9	0.8	0.9	0.9	1.0	0.8	1.0	1.4	4.0	7.6	8.3

[1] RI = Recurrence interval, years

Table 15
Wave Heights for Plan 3G; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.2	0.2	0.6	0.2	0.5	0.8	0.4	0.4	0.7	0.5	0.9	1.5	2.9	3.9	5.0
5	5.8	7.1	0.3	0.3	0.4	0.6	0.4	0.8	1.0	0.6	0.7	1.1	0.7	1.3	2.0	3.5	5.1	6.4
20	6.4	9.1	0.5	0.5	0.9	0.9	1.0	1.1	1.3	1.1	1.2	1.5	1.1	1.7	2.3	4.2	6.7	7.8
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.4	0.3	0.3	1.0	0.8	1.4	1.4	0.8	0.9	1.1	1.2	1.7	2.2	3.9	5.4	6.6
5	6.3	8.4	0.5	0.4	0.5	1.2	1.1	1.6	1.4	1.1	1.3	1.3	1.5	2.2	2.5	4.2	6.4	7.2
20	6.7	10.0	0.7	0.6	0.8	1.4	1.5	2.1	1.8	1.5	1.8	1.6	1.8	2.6	2.9	4.9	8.0	8.6

[1] RI = Recurrence interval, years

Table 16
Wave Heights for Plan 3H; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.1	0.1	0.1	0.1	0.6	0.1	0.2	0.5	0.1	0.8	1.3	2.2	3.9	5.1
5	5.8	7.1	0.3	0.2	0.3	0.2	0.4	0.4	0.7	0.4	0.6	0.8	0.5	1.1	1.5	2.7	4.9	6.4
20	6.4	9.1	0.6	0.4	0.7	0.6	1.0	0.8	1.0	0.8	1.1	1.3	0.9	1.5	1.9	3.4	6.6	7.8
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.3	0.2	0.2	0.8	0.7	1.1	1.1	0.7	0.8	0.9	1.0	1.4	1.7	2.9	5.0	6.2
5	6.3	8.4	0.4	0.3	0.4	1.1	1.0	1.5	1.3	0.9	1.2	1.1	1.3	2.1	2.2	3.7	6.3	7.3
20	6.7	10.0	0.7	0.5	0.8	1.4	1.4	1.8	1.5	1.3	1.7	1.4	1.6	2.5	2.6	4.3	7.8	8.8

[1] RI = Recurrence interval, years

Table 17
Wave Heights for Plan 3I; Initial Test Waves from 34 Degrees

	Test Wave		Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.1	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.4	0.5	2.4	4.0	4.9
5	5.8	7.1	0.2	0.2	0.3	0.4	0.7	0.4	0.5	0.5	0.6	0.5	0.4	0.7	1.1	2.8	5.8	6.6
20	6.4	9.1	0.4	0.4	0.8	0.7	1.2	0.9	0.9	0.9	0.9	1.0	0.8	1.2	1.9	4.0	7.1	7.9
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.1	0.2	0.4	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.7	1.1	2.4	5.6	6.1
5	6.3	8.4	0.3	0.2	0.5	0.7	0.8	0.9	0.7	0.7	0.7	0.8	0.8	1.3	2.0	3.3	7.0	7.2
20	6.7	10.0	0.5	0.5	0.8	1.0	1.2	1.4	1.1	1.2	1.3	1.3	1.3	1.9	2.7	4.8	7.6	8.1

[1] RI = Recurrence interval, years

Table 18
Wave Heights for Plan 3J; Initial Test Waves from 34 Degrees

	Test Wave		Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.2	0.3	0.3	0.3	0.5	0.4	0.3	0.3	0.2	0.6	1.1	2.8	5.4	4.4
5	5.8	7.1	0.2	0.2	0.4	0.4	0.7	0.5	0.5	0.7	0.7	0.5	0.4	0.6	1.4	3.4	5.6	6.4
20	6.4	9.1	0.5	0.6	0.9	0.8	1.2	1.0	1.0	1.1	1.1	1.2	0.9	1.2	2.4	4.3	6.8	7.6
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.2	0.5	0.5	0.6	0.7	0.5	0.5	0.6	0.5	0.8	1.7	2.8	5.5	6.1
5	6.3	8.4	0.4	0.3	0.5	0.7	0.9	1.0	0.9	0.8	0.8	0.9	0.7	1.2	2.3	3.2	6.8	7.1
20	6.7	10.0	0.6	0.5	0.8	1.1	1.3	1.5	1.4	1.3	1.4	1.5	1.3	1.8	3.1	4.7	7.8	7.8

[1] RI = Recurrence interval, years

Table 19
Wave Heights for Plan 3K; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.2	0.3	0.3	0.3	0.4	0.3	0.3	0.2	0.2	0.4	0.9	2.5	4.1	4.8
5	5.8	7.1	0.3	0.3	0.4	0.5	0.6	0.5	0.6	0.6	0.7	0.5	0.4	0.7	1.6	3.1	5.6	6.5
20	6.4	9.1	0.5	0.5	0.8	0.7	1.2	0.9	0.9	1.1	1.1	1.0	0.9	1.1	2.3	4.0	7.1	7.6
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.2	0.5	0.5	0.6	0.7	0.5	0.5	0.5	0.5	0.8	1.8	2.8	5.7	6.1
5	6.3	8.4	0.4	0.3	0.5	0.7	0.9	0.9	0.9	0.8	0.8	0.7	0.7	1.2	2.3	3.2	6.8	7.0
20	6.7	10.0	0.6	0.6	0.8	1.1	1.3	1.5	1.4	1.3	1.4	1.3	1.2	1.7	3.0	4.8	7.9	7.0

[1] RI = Recurrence interval, years

Table 20
Wave Heights for Plan 4; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.1	0.2	0.2	0.1	0.7	0.2	0.1	0.5	0.1	1.0	1.2	2.4	3.9	4.8
5	5.8	7.1	0.2	0.1	0.3	0.3	0.4	0.4	1.0	0.4	0.5	0.9	0.4	1.5	2.0	3.4	5.7	6.7
20	6.4	9.1	0.4	0.2	0.7	0.7	0.9	0.8	1.3	0.8	0.8	1.3	0.8	1.8	2.6	4.1	7.0	7.8
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.1	0.1	0.1	0.5	0.5	0.7	1.0	0.3	0.3	1.1	0.7	1.5	2.2	3.6	5.4	6.2
5	6.3	8.4	0.2	0.1	0.3	0.8	0.9	1.0	1.2	0.5	0.8	1.2	0.9	1.8	2.5	4.2	7.0	7.5
20	6.7	10.0	0.4	0.3	0.7	1.1	1.1	1.3	1.5	0.8	1.0	1.5	1.1	2.0	3.0	4.6	8.1	8.9

[1] RI = Recurrence interval, years

Table 21
Wave Heights for Plan 4A; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.1	0.1	0.1	0.2	0.3	0.2	0.4	0.3	0.3	0.4	0.3	0.6	0.8	2.0	4.0	4.8
5	5.8	7.1	0.3	0.2	0.3	0.4	0.5	0.5	0.7	0.5	0.6	0.7	0.5	0.9	1.4	2.1	5.2	6.2
20	6.4	9.1	0.5	0.5	0.7	0.9	1.0	0.9	1.3	0.9	1.0	1.2	1.2	1.8	2.7	3.6	7.0	7.4
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.2	0.2	0.4	0.4	0.4	0.6	0.4	0.5	0.6	0.6	0.8	1.4	2.0	5.4	5.8
5	6.3	8.4	0.3	0.3	0.4	0.7	0.8	0.9	1.0	0.7	0.8	0.9	0.9	1.3	2.2	2.7	6.9	7.0
20	6.7	10.0	0.5	0.5	0.7	1.2	1.2	1.5	1.5	1.1	1.3	1.5	1.4	2.3	3.5	4.6	7.7	7.9

[1] RI = Recurrence interval, years

Table 22
Wave Heights for Plan 4B; Initial Test Waves from 34 Degrees

Test Wave			Wave Height, ft, at Indicated Gauge Location															
RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																		
2	5.4	5.2	0.2	0.1	0.1	0.3	0.2	0.3	0.5	0.3	0.2	0.4	0.3	0.7	1.1	2.3	3.8	4.6
5	5.8	7.1	0.3	0.2	0.3	0.4	0.5	0.5	0.7	0.5	0.5	0.6	0.5	0.9	1.6	2.8	5.8	6.4
20	6.4	9.1	0.4	0.4	0.7	0.7	0.9	1.0	1.1	0.9	0.9	1.2	0.9	1.8	3.0	4.1	7.4	7.7
All-Season Waves, swl = +4.7 ft LWD																		
2	6.0	6.9	0.2	0.1	0.2	0.3	0.5	0.4	0.5	0.4	0.4	0.5	0.4	0.7	1.5	2.0	5.5	6.0
5	6.3	8.4	0.3	0.2	0.4	0.6	0.8	0.8	0.8	0.6	0.6	0.8	0.6	1.1	2.4	2.9	6.9	7.1
20	6.7	10.0	0.5	0.4	0.7	0.9	1.1	1.2	1.2	1.0	1.0	1.3	1.2	1.9	3.7	4.9	7.8	8.3

[1] RI = Recurrence interval, years

Table 23
Wave Heights for Existing Conditions; Refined Test Waves

Direction deg	Test Wave			Wave Height, ft, at Indicated Gauge Location															
	RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																			
49	5	5.8	7.1	0.7	0.3	0.5	1.9	1.0	1.6	3.0	1.0	1.2	2.4	2.6	4.0	4.0	4.9	6.2	6.3
	20	6.4	9.1	0.7	0.6	0.7	2.2	1.4	1.9	3.3	1.5	1.7	3.3	3.3	4.4	4.8	5.6	7.7	7.5
	50	6.7	10.0	0.8	0.7	0.8	2.2	1.7	2.1	3.5	1.7	2.0	3.7	3.6	4.7	5.3	5.7	7.8	8.1
34	5	5.0	5.2	0.2	0.1	0.1	1.1	0.2	0.6	2.2	0.2	0.4	1.1	1.1	1.4	1.8	1.9	3.4	4.4
	20	5.8	7.2	0.4	0.4	0.5	1.7	1.0	1.3	2.7	0.8	1.0	2.7	2.5	3.2	4.0	3.0	5.5	6.5
	50	6.1	8.3	0.5	0.5	0.5	1.7	1.2	1.6	2.8	1.2	1.4	2.9	2.9	3.6	4.2	3.2	6.6	6.7
354	5	5.7	6.0	0.3	0.1	0.1	1.3	0.6	1.4	1.9	0.7	0.7	2.7	1.7	2.9	3.3	3.3	4.1	5.1
	20	6.3	7.4	0.5	0.4	0.5	1.7	1.2	1.8	2.7	1.3	1.6	3.2	2.6	4.2	4.4	4.3	5.6	6.8
	50	6.5	8.0	0.6	0.5	0.6	1.9	1.4	2.0	3.1	1.6	1.7	2.9	2.7	4.2	4.3	4.4	5.7	7.3
All-Season Waves, swl = +4.7 ft LWD																			
49	5	6.3	8.4	0.6	0.4	0.5	2.1	1.5	2.3	3.1	1.3	1.5	2.8	2.7	3.7	4.2	5.5	7.3	7.1
	20	6.7	10.0	0.7	0.6	0.7	2.1	1.8	2.2	3.2	1.4	1.8	3.5	3.4	4.1	4.9	6.4	8.7	8.2
	50	7.0	10.6	0.7	0.7	0.8	2.0	2.0	2.4	3.3	1.6	2.0	3.6	3.6	4.0	5.1	6.4	9.3	8.7
34	5	5.4	6.5	0.3	0.3	0.2	1.6	0.8	2.1	2.5	0.6	0.9	2.2	2.5	2.4	3.1	2.7	5.3	5.7
	20	6.3	8.5	0.5	0.5	0.5	1.8	1.4	2.0	2.9	1.0	1.6	2.6	3.3	3.1	3.6	3.1	6.6	6.6
	50	6.6	9.7	0.6	0.6	0.7	2.1	1.8	2.4	2.9	1.2	1.9	2.9	3.7	3.6	4.0	3.9	7.3	7.5
354	5	6.0	6.9	0.3	0.2	0.2	1.6	1.2	1.7	2.6	1.0	1.1	2.9	2.3	3.6	4.0	4.8	5.4	6.5
	20	6.4	7.6	0.3	0.3	0.4	1.9	1.7	2.1	3.1	1.2	1.4	2.9	2.7	3.7	4.0	4.9	5.8	7.0
	50	6.5	8.0	0.3	0.4	0.4	1.8	1.9	2.2	3.2	1.2	1.6	2.7	3.0	3.7	4.1	4.9	6.0	7.5

[1] RI = Recurrence interval, years.

Table 24
Wave Heights for Plans 3L - 3R for 5.8-sec, 7.2-ft, 20-Year Navigation Season Test Waves From 34 Degrees; swl = +2.5 ft LWD

Plan	Wave Height (ft) at Indicated Gauge Location															
	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
3L	0.2	0.2	0.4	0.5	0.5	0.6	0.9	0.6	0.7	0.8	0.5	1.2	3.4	2.6	5.3	6.1
3M	0.3	0.2	0.4	0.6	0.6	0.6	0.9	0.6	0.7	0.8	0.5	1.2	3.4	2.6	5.5	6.2
3N	0.2	0.1	0.4	0.6	0.6	0.6	1.0	0.6	0.7	0.8	0.5	1.3	3.5	2.6	5.5	6.2
3O	0.3	0.2	0.4	0.7	0.5	0.6	1.0	0.6	0.8	0.8	0.5	1.3	3.2	2.6	5.4	6.2
3P	0.2	0.1	0.4	0.7	0.5	0.6	0.9	0.6	0.7	0.7	0.4	1.1	3.3	3.0	5.5	6.2
3Q	0.3	0.2	0.4	0.8	0.6	0.7	1.1	0.6	0.7	0.7	0.5	1.3	3.5	3.2	5.7	6.4
3R	0.3	0.2	0.4	0.7	0.6	0.7	1.1	0.6	0.7	0.7	0.5	1.3	3.0	3.1	5.6	6.3

Table 25
Wave Heights for Plans 4C - 4F for 5.8-sec, 7.2-ft, 20-Year Navigation Season Test Waves From 34 Degrees; swl = +2.5 ft LWD

Plan	Wave Height (ft) at Indicated Gauge Location															
	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
4C	0.2	0.2	0.4	0.5	0.5	0.4	0.8	0.4	0.5	0.7	0.6	1.3	1.9	2.4	5.5	6.2
4D	0.3	0.2	0.3	0.9	0.5	0.8	1.5	0.7	0.8	1.4	1.0	1.7	2.6	2.4	5.2	6.0
4E	0.4	0.3	0.4	1.0	0.6	0.8	1.7	0.7	0.9	0.8	1.1	1.9	2.9	2.7	5.7	6.4
4F	0.3	0.3	0.4	1.0	0.6	0.8	1.7	0.7	0.9	1.2	0.9	1.9	3.1	2.6	5.1	6.1

Table 26
Wave Heights for Plans 3L, 3O, 3R - 3DD and Plan 4C for 6.4-sec, 9.1-ft, 20-Year Navigation Season Test Waves From 49 Degrees; swl = +2.5 ft LWD

Plan	Wave Height (ft) at Indicated Gauge Location															
	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
3L	0.5	0.5	0.8	0.8	1.0	1.0	1.1	1.0	1.2	1.3	0.9	1.5	4.2	5.0	7.4	7.3
3O	0.5	0.4	0.7	0.9	1.1	1.1	1.4	1.0	1.2	1.5	0.9	1.9	4.4	5.1	7.4	7.3
3R	0.5	0.5	0.7	1.1	1.0	1.3	1.7	1.1	1.2	1.5	1.1	2.5	4.7	4.8	7.4	7.3
3S	0.4	0.4	0.8	0.8	1.0	1.0	1.2	1.0	1.1	1.0	0.9	1.5	4.2	5.0	7.4	7.6
3T	0.4	0.4	0.8	0.8	1.0	1.0	1.1	0.9	1.1	1.2	0.8	1.5	4.3	4.9	7.5	7.6
3U	0.4	0.4	0.8	0.8	1.0	1.0	1.1	0.8	1.0	0.9	0.7	1.5	4.2	5.1	7.5	7.3
3V	0.5	0.5	0.9	0.7	1.0	1.0	1.0	0.9	1.1	1.1	0.8	1.3	3.1	5.3	7.3	7.5
3W	0.5	0.5	0.9	0.7	1.0	0.9	0.9	0.8	1.1	1.0	0.8	1.2	3.0	5.2	7.5	7.6
3X	0.3	0.3	0.5	0.5	1.0	0.8	0.7	0.6	0.8	1.0	0.7	1.0	2.4	4.8	7.4	7.5
3Y	0.3	0.3	0.4	0.5	0.9	0.8	0.7	0.6	0.8	1.1	0.7	1.1	2.7	5.0	7.2	7.3
3Z	0.3	0.3	0.4	0.5	0.9	0.8	0.8	0.6	0.9	0.8	0.6	1.1	2.7	5.4	7.5	7.4
3AA	0.3	0.3	0.4	0.6	0.9	0.8	0.9	0.7	1.0	1.2	0.8	1.3	3.4	5.3	7.3	7.5
3BB	0.3	0.3	0.4	0.6	0.8	0.8	0.9	0.7	0.9	0.8	0.7	1.2	3.6	5.3	7.3	7.6
3CC	0.3	0.5	0.7	0.8	1.0	0.9	1.2	0.8	1.1	1.4	0.9	1.5	4.6	5.3	7.5	7.4
3DD	0.3	0.4	0.7	0.8	1.0	0.9	1.2	0.8	1.0	1.0	0.8	1.5	4.7	5.2	7.3	7.3
4C	0.5	0.3	0.7	1.3	1.1	1.6	2.3	1.0	1.1	1.9	1.4	2.9	3.2	4.9	7.8	7.5

Table 27
Wave Heights for Plan 3BB; Refined Test Waves

Direction deg	Test Wave			Wave Height, ft, at Indicated Gauge Location															
	RI[1]	Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14	Gauge 15	Gauge 16
Navigation Season Waves, swl = +2.5 ft LWD																			
49	5	5.8	7.1	0.2	0.2	0.4	0.6	0.5	0.6	0.8	0.5	0.6	0.5	0.5	1.0	2.7	4.6	6.4	6.3
	20	6.4	9.1	0.3	0.3	0.4	0.6	0.8	0.8	0.9	0.7	0.9	0.8	0.7	1.2	3.6	5.3	7.3	7.6
	50	6.7	10.0	0.5	0.4	0.7	0.8	1.1	1.0	1.0	1.0	1.2	1.1	1.0	1.5	3.9	5.6	7.4	8.1
34	5	5.0	5.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.4	1.7	1.9	3.5	4.1
	20	5.8	7.2	0.1	0.1	0.3	0.4	0.4	0.3	0.6	0.5	0.6	0.4	0.3	0.9	2.9	2.7	5.8	6.1
	50	6.1	8.3	0.1	0.1	0.5	0.6	0.6	0.5	0.8	0.6	0.7	0.5	0.6	1.1	3.3	3.3	6.6	6.6
354	5	5.7	6.0	0.1	0.1	0.1	0.3	0.3	0.3	0.6	0.3	0.3	0.3	0.3	0.7	2.0	3.6	4.3	5.2
	20	6.3	7.4	0.3	0.1	0.3	0.6	0.6	0.6	0.8	0.5	0.7	0.6	0.6	1.1	2.8	4.2	5.3	6.6
	50	6.5	8.0	0.3	0.2	0.4	0.7	0.7	0.7	0.8	0.7	0.8	0.7	0.7	1.2	3.1	4.0	5.7	7.3
All-Season Waves, swl = +4.7 ft LWD																			
49	5	6.3	8.4	0.2	0.2	0.4	0.7	0.9	1.0	0.9	0.6	0.8	0.8	0.8	1.1	3.4	5.2	7.3	7.1
	20	6.7	10.0	0.4	0.3	0.6	1.0	1.1	1.3	1.2	0.9	1.3	1.0	1.1	1.5	3.9	6.5	8.3	8.2
	50	7.0	10.6	0.7	0.6	1.0	1.0	1.4	1.5	1.2	1.2	1.4	1.4	1.2	1.6	4.0	6.5	8.9	8.6
34	5	5.4	6.5	0.1	0.1	0.1	0.4	0.3	0.5	0.6	0.2	0.4	0.2	0.3	0.9	2.7	2.2	5.3	5.5
	20	6.3	8.5	0.2	0.2	0.4	0.9	0.9	1.1	1.1	0.7	1.0	0.7	0.9	1.5	3.8	3.3	6.6	6.6
	50	6.6	9.7	0.3	0.3	0.5	1.1	1.1	1.5	1.3	0.9	1.2	1.0	1.1	1.7	4.1	4.0	7.1	7.4
354	5	6.0	6.9	0.2	0.2	0.2	0.6	0.5	0.8	0.8	0.5	0.6	0.5	0.7	1.2	2.4	4.3	5.1	6.2
	20	6.4	7.6	0.3	0.3	0.3	0.7	0.7	1.0	0.9	0.7	0.8	0.7	0.8	1.4	2.6	4.3	5.6	6.8
	50	6.5	8.0	0.3	0.3	0.3	0.9	0.8	1.1	1.1	0.8	0.9	0.8	0.9	1.4	2.9	4.6	5.9	7.5

[1] RI = Recurrence interval, years.

Table 28
Water Surface Elevations (el) and River Current Velocities for Existing Conditions and Plan 3BB; swl = +2.5 ft LWD = 245.3 IGLD 1955

Station	Existing Conditions		Plan 3BB	
	Water Surface, el, ft	River Current Velocity, ft/sec	Water Surface, el, ft	River Current Velocity, ft/sec
2 yr Discharge				
5200	245.4	4.0	245.4	3.8
4000	245.4	2.7	245.4	2.8
3000	245.4	2.7	245.4	2.6
2500	245.4	2.5	245.4	2.9
2000	245.3	2.5	245.3	2.9
1000	245.3	2.4	245.3	2.9
0	245.3	2.4	245.3	2.5
10 yr Discharge				
5200	245.5	5.6	245.5	5.4
4000	245.5	3.9	245.5	4.3
3000	245.5	3.3	245.5	4.0
2500	245.4	3.5	245.4	4.1
2000	245.4	3.5	245.4	3.9
1000	245.3	3.5	245.3	3.8
0	245.3	3.2	245.3	3.3
100 yr Discharge				
5200	245.5	7.3	245.7	6.7
4000	245.6[1]	5.5	245.7	4.9
3000	245.5	5.0	245.6	5.2
2500	245.5	4.7	245.5	5.6
2000	245.4	4.6	245.4	5.5
1000	245.3	4.4	245.3	5.0
0	245.3	4.3	245.3	4.5

[1] El increase due to turbulence caused by swing bridge pier.

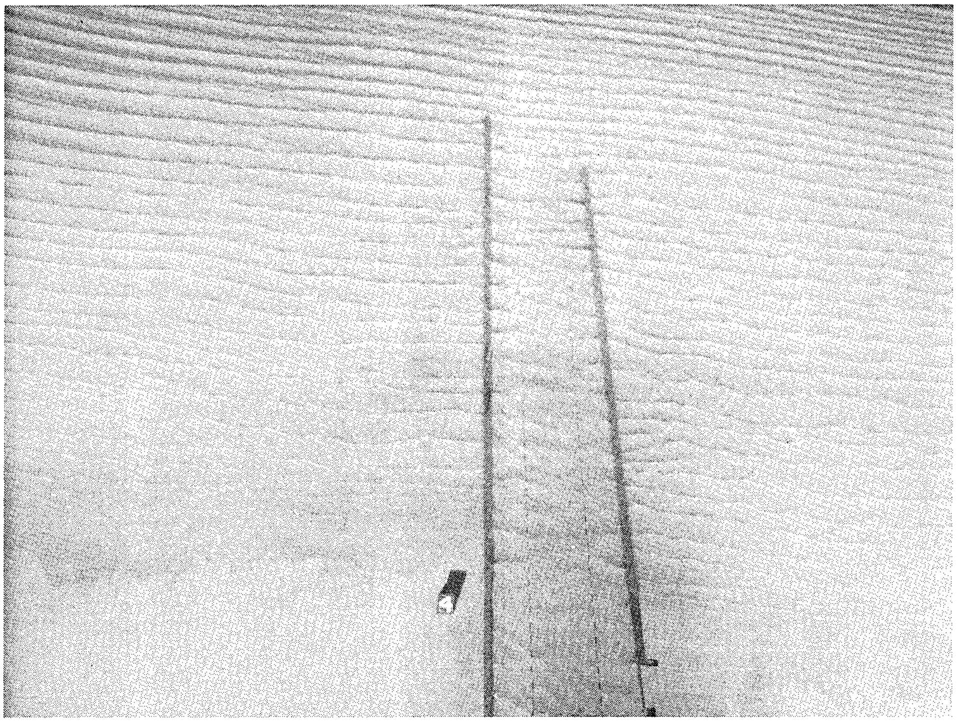


Photo 1. Typical wave patterns for existing conditions; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

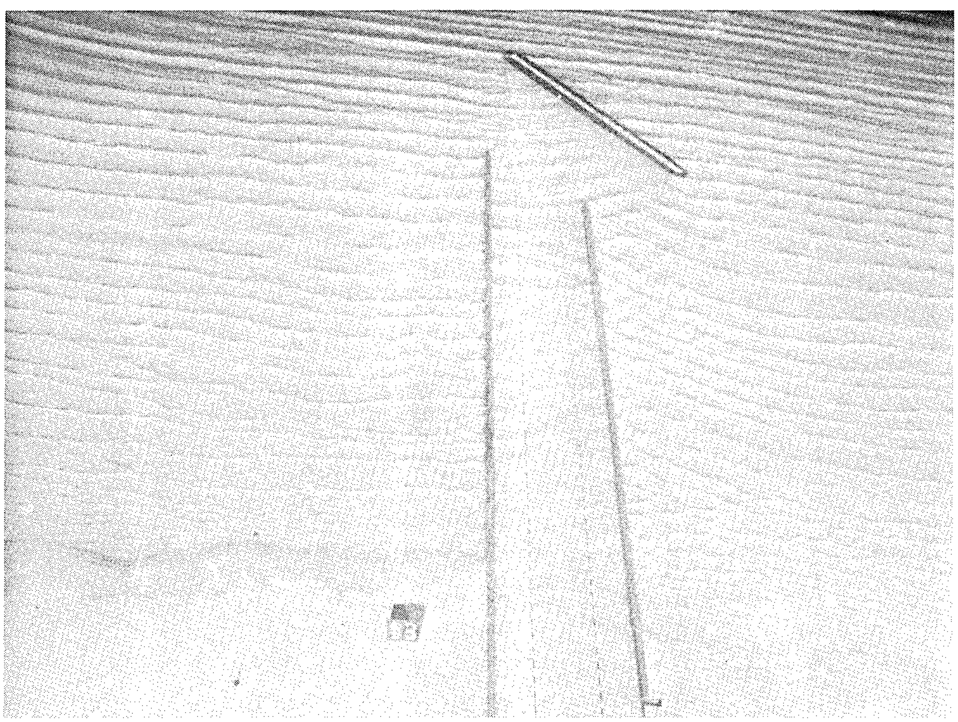


Photo 2. Typical wave patterns for Plan 1; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

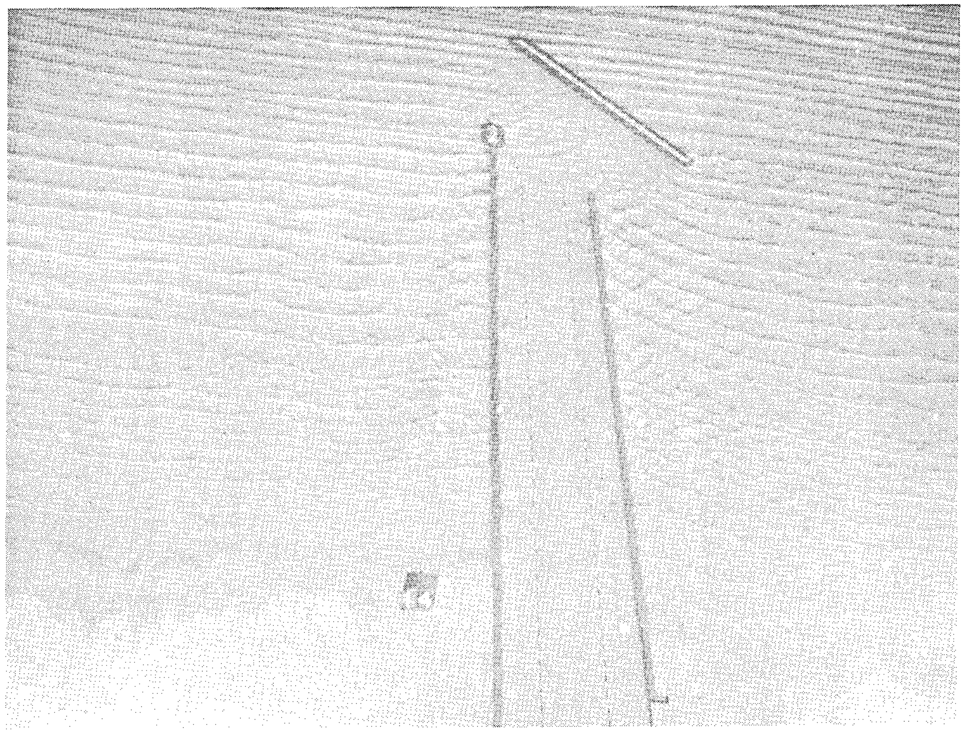


Photo 3. Typical wave patterns for Plan 1A; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

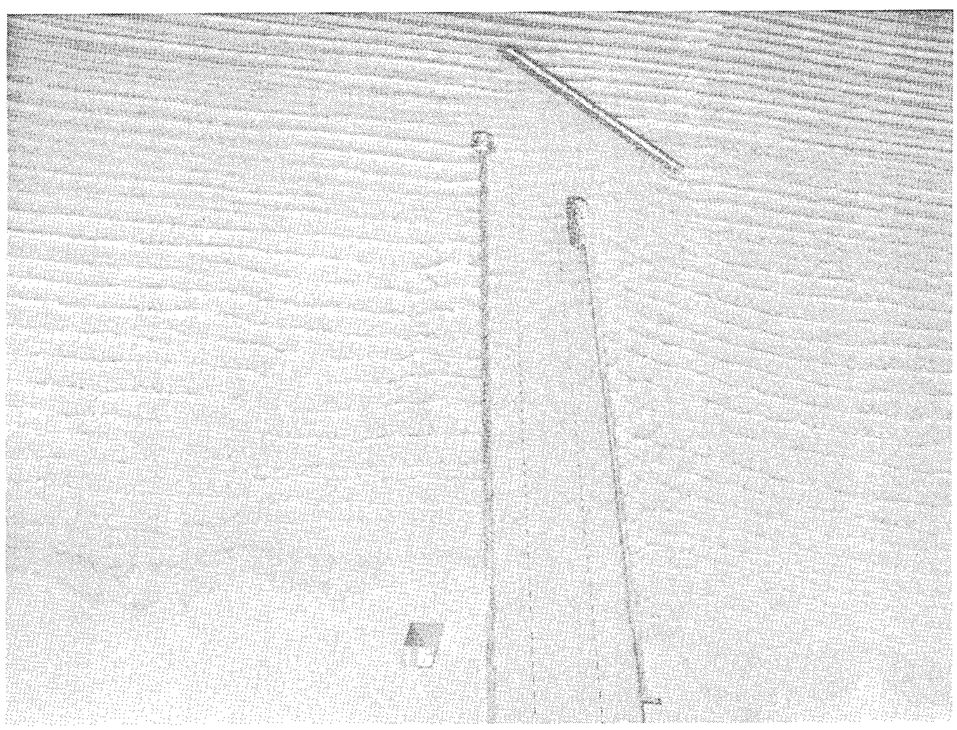


Photo 4. Typical wave patterns for Plan 1B; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

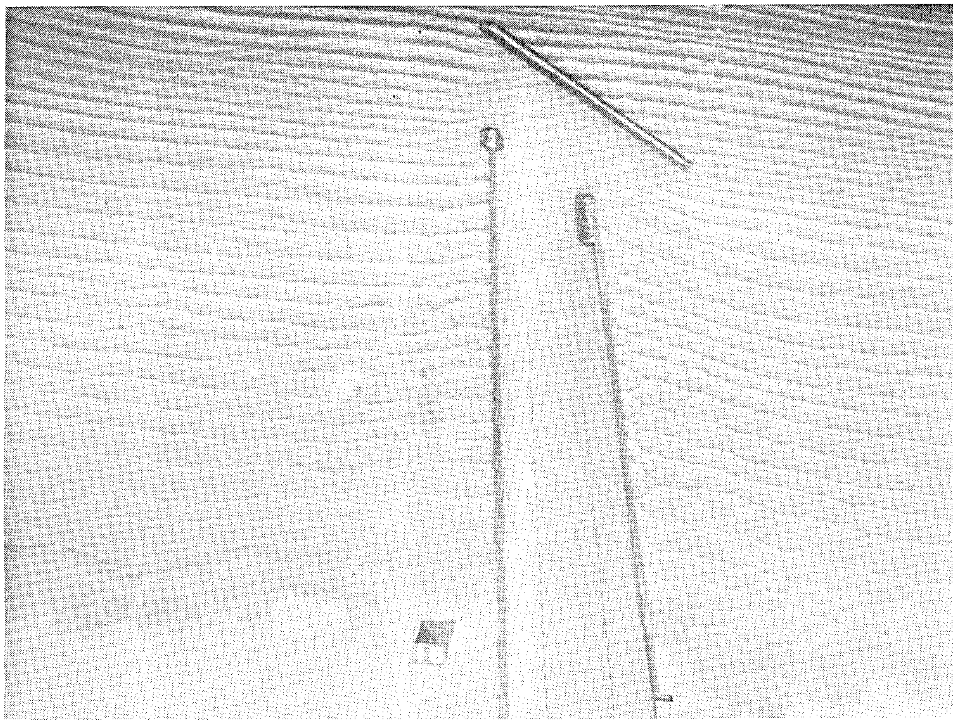


Photo 5. Typical wave patterns for Plan 1C; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

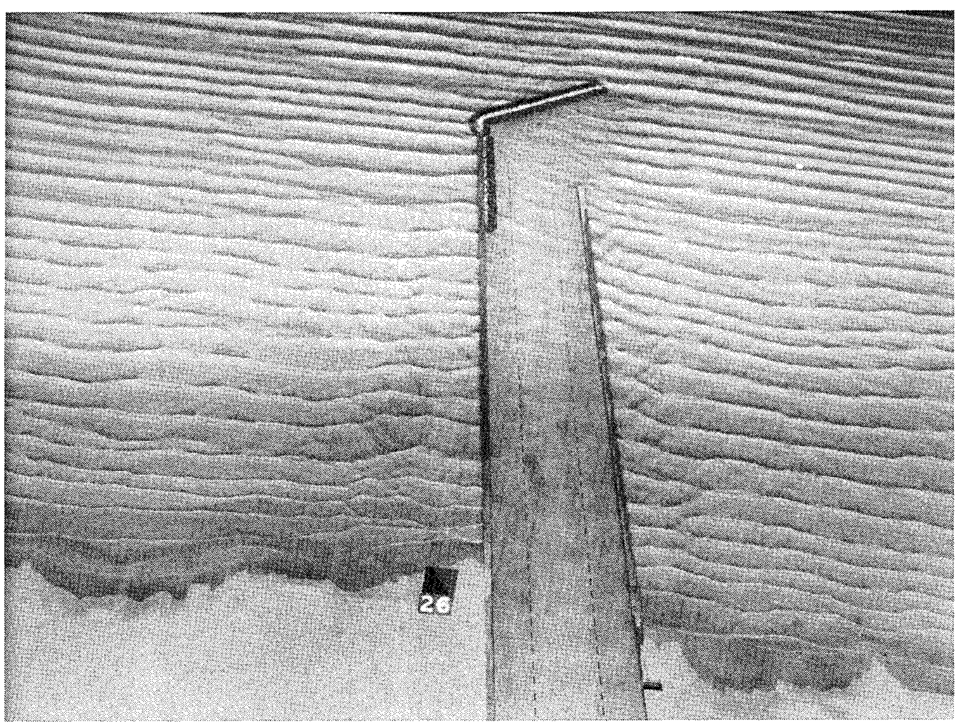


Photo 6. Typical wave patterns for Plan 2; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

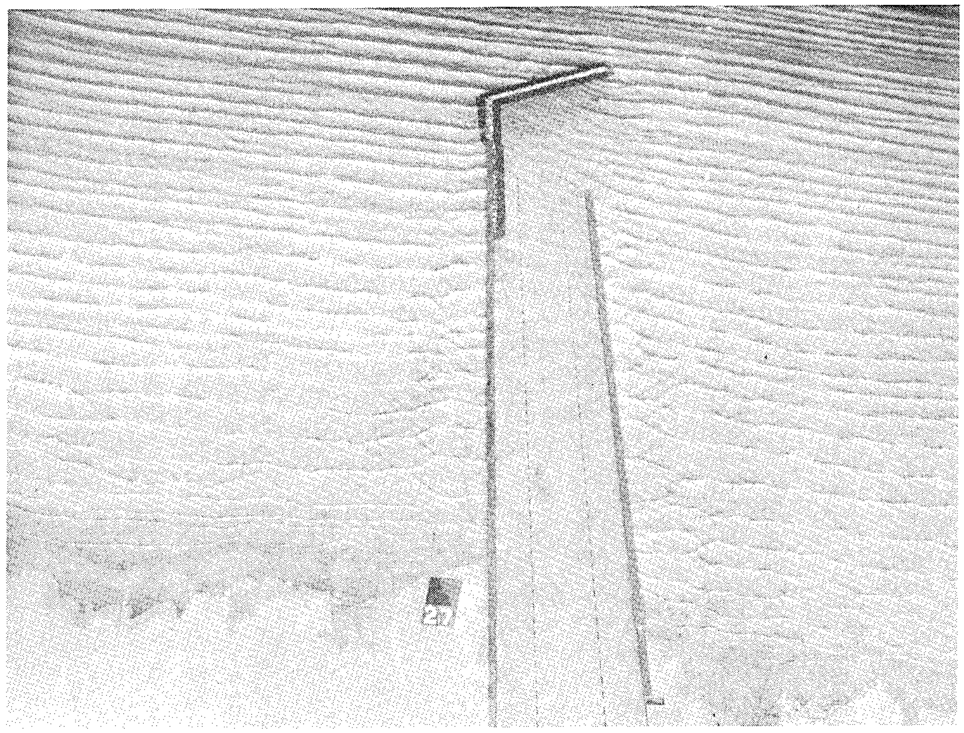


Photo 7. Typical wave patterns for Plan 2A; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

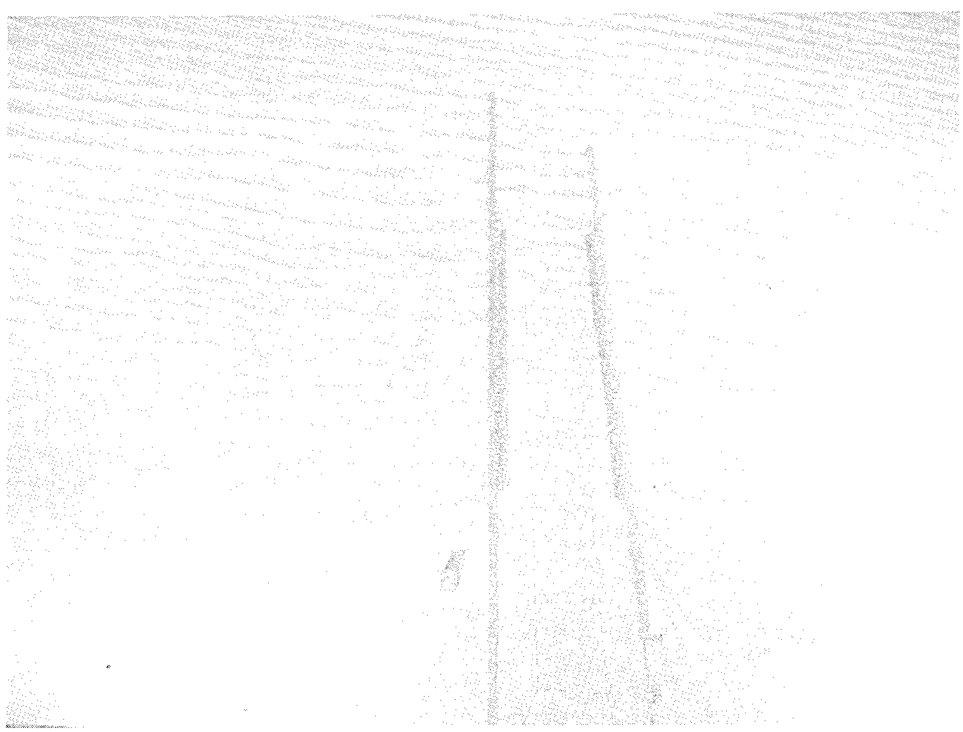


Photo 8. Typical wave patterns for Plan 3; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

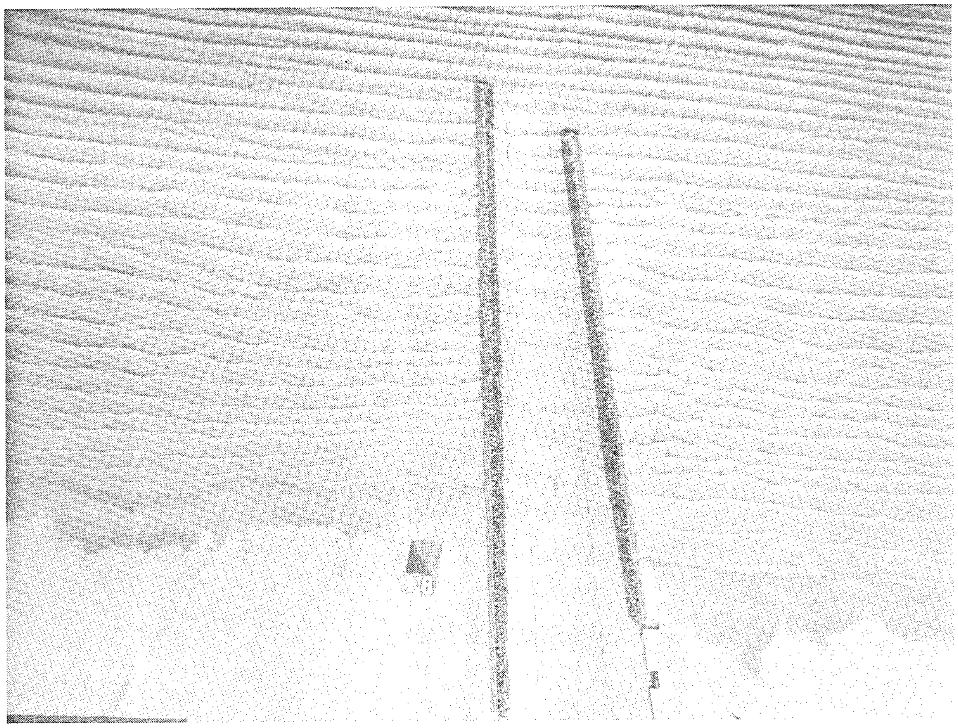


Photo 9. Typical wave patterns for Plan 3A; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

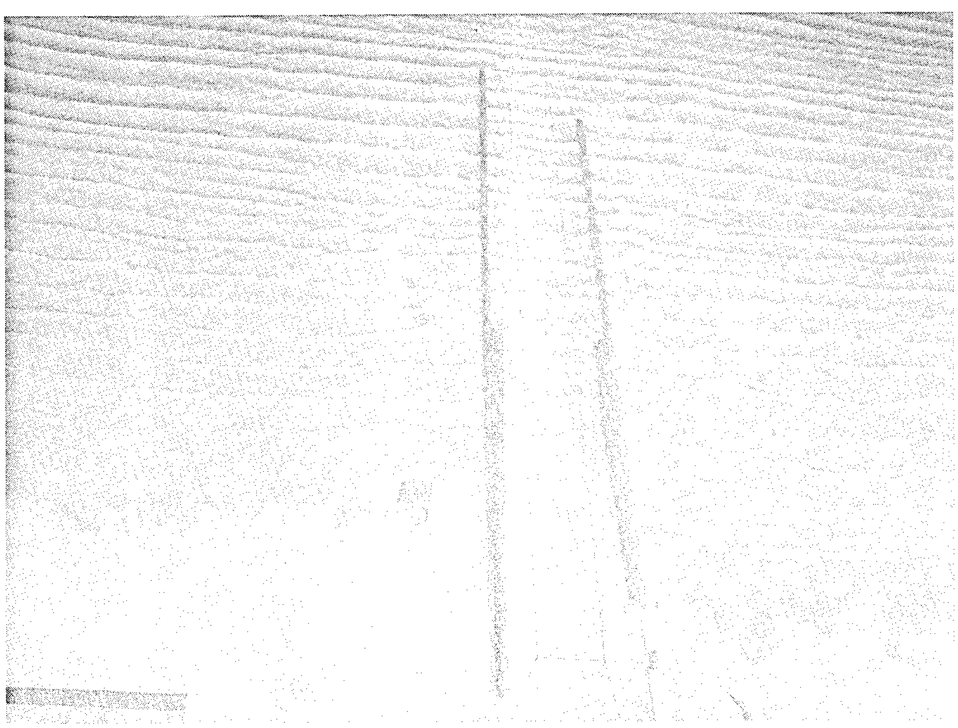


Photo 10. Typical wave patterns for Plan 3B; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

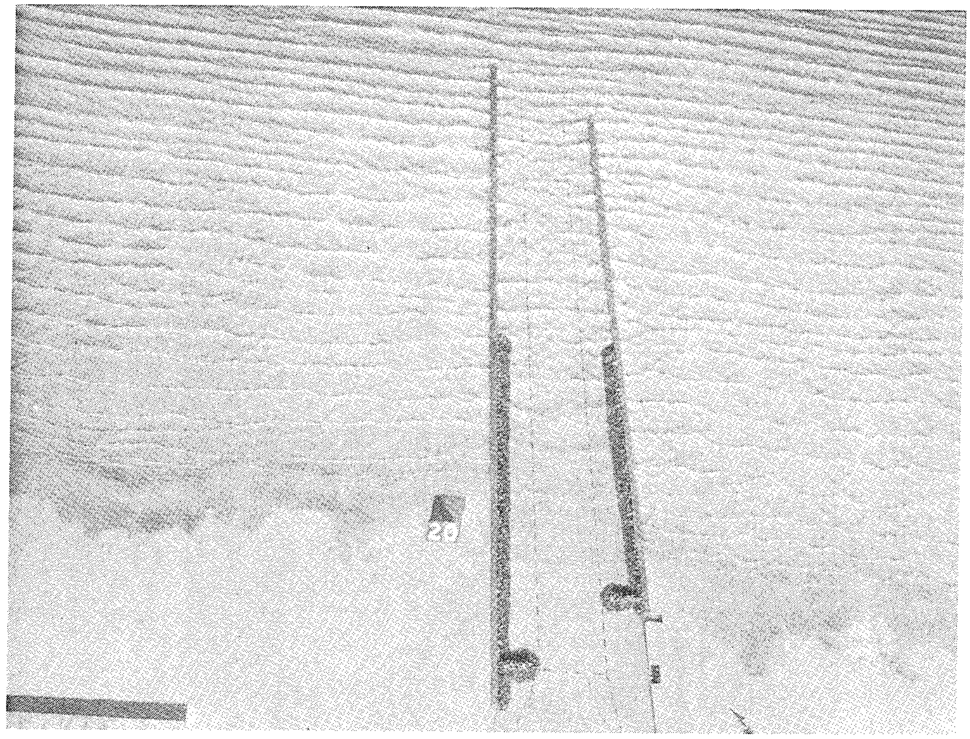


Photo 11. Typical wave patterns for Plan 3C; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

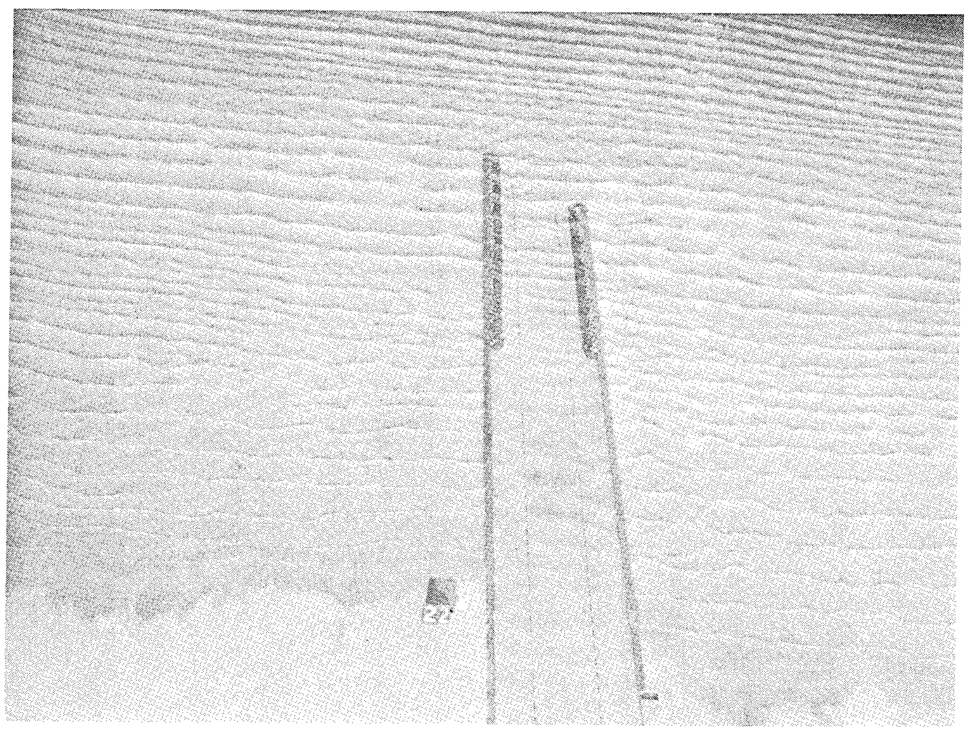


Photo 12. Typical wave patterns for Plan 3D; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

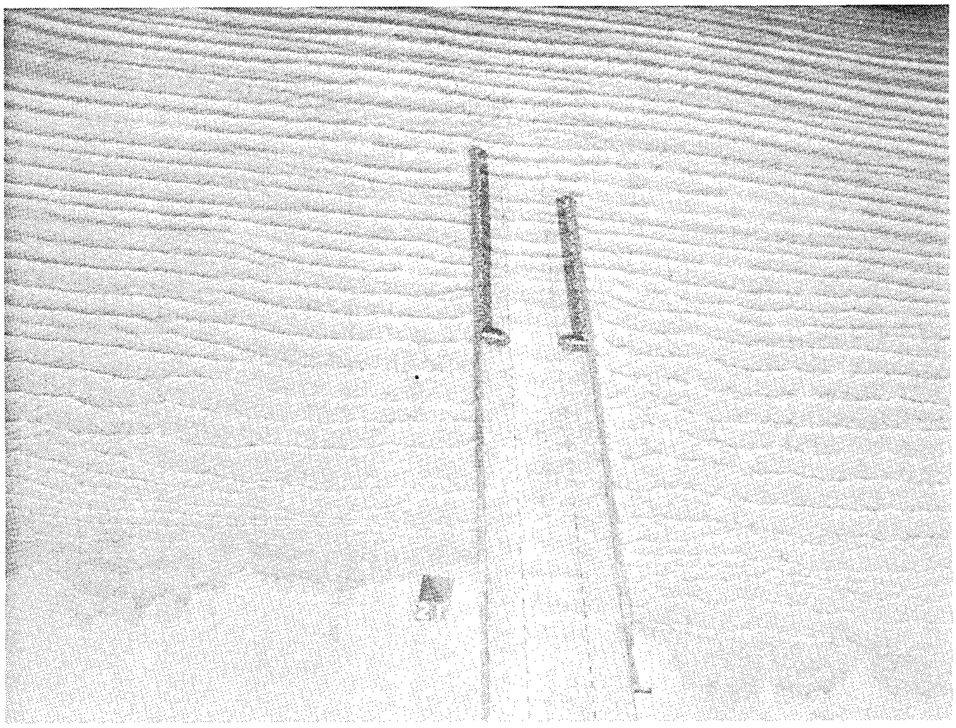


Photo 13. Typical wave patterns for Plan 3E; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

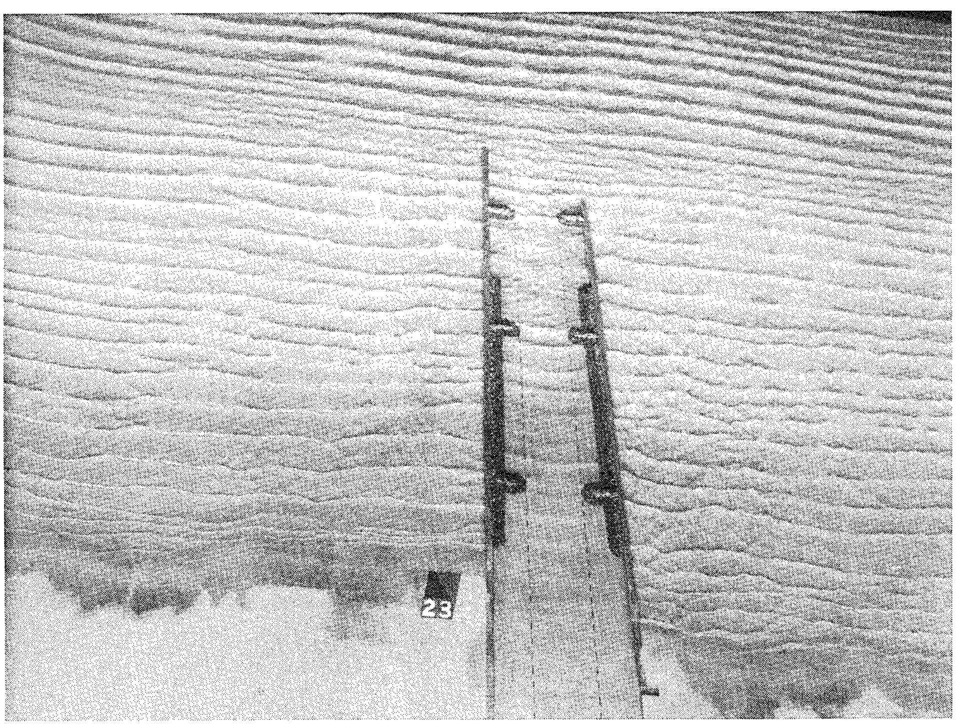


Photo 14. Typical wave patterns for Plan 3F; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

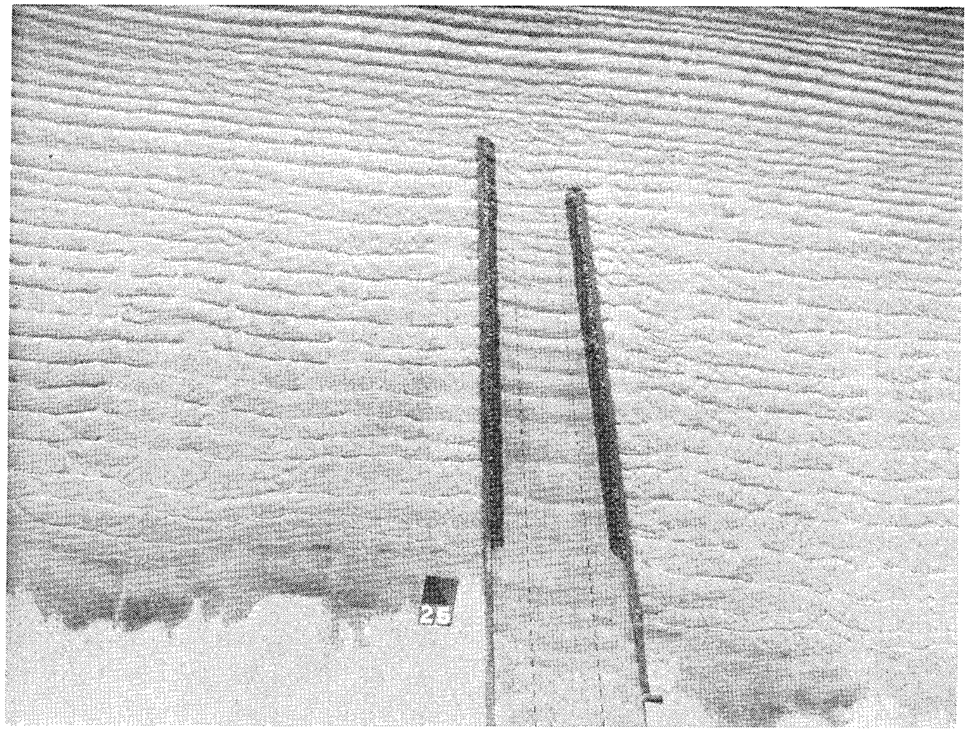


Photo 15. Typical wave patterns for Plan 3G; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

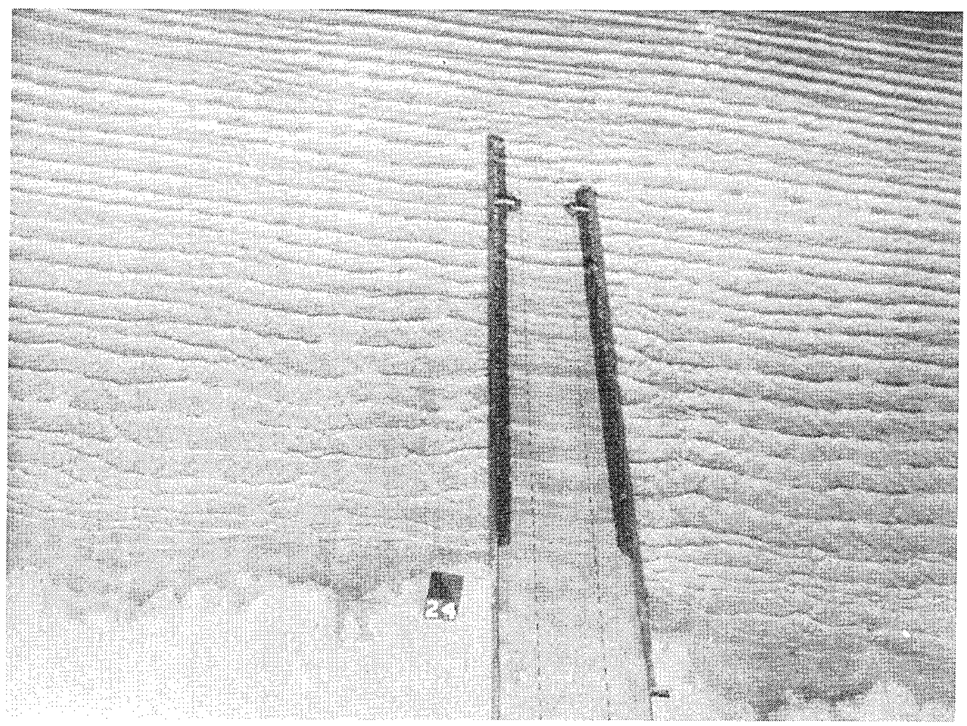


Photo 16. Typical wave patterns for Plan 3H; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

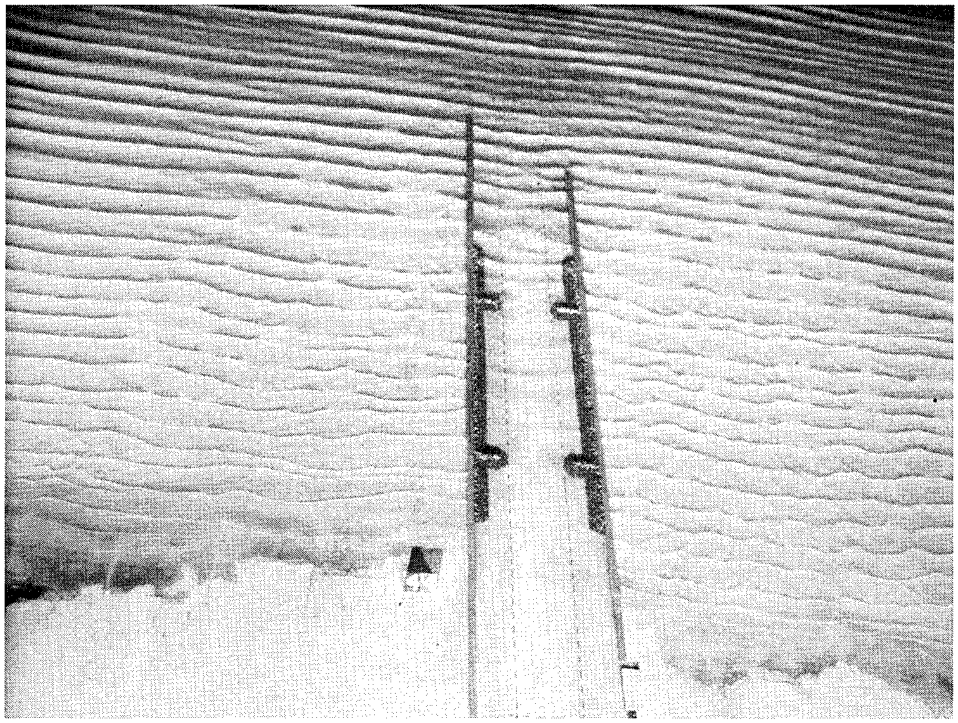


Photo 17. Typical wave patterns for Plan 3I; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

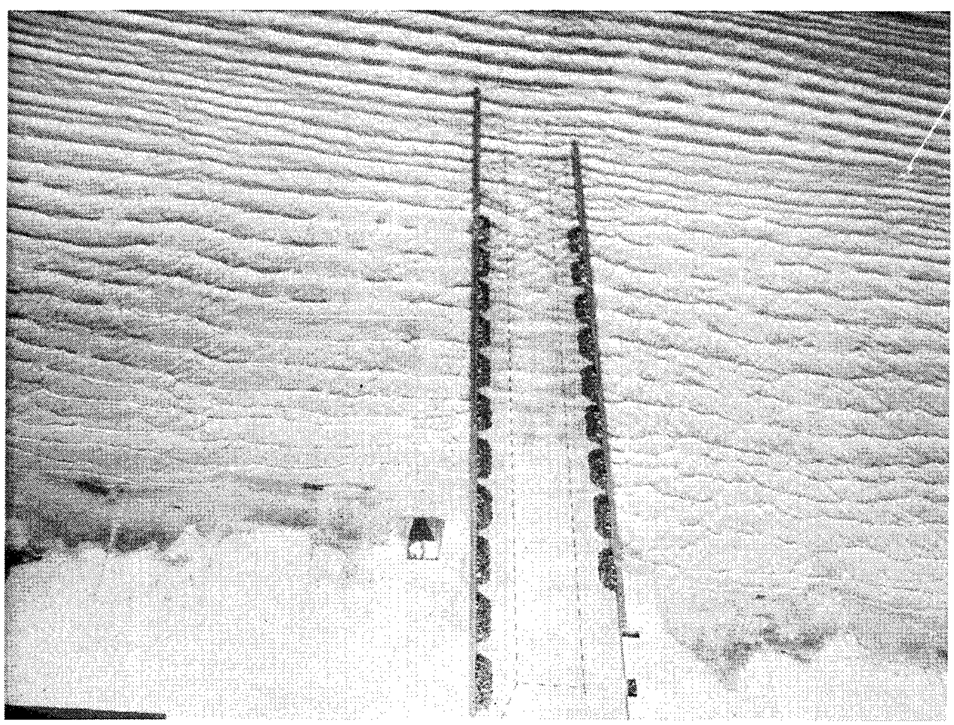


Photo 18. Typical wave patterns for Plan 3J; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

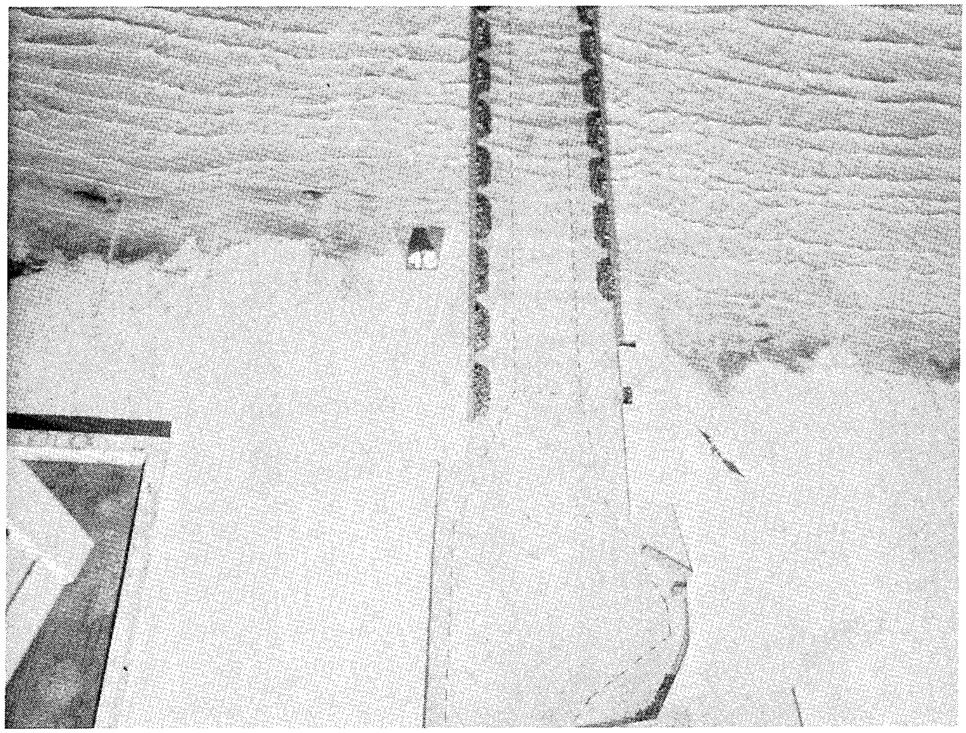


Photo 19. Typical wave patterns for Plan 3K; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

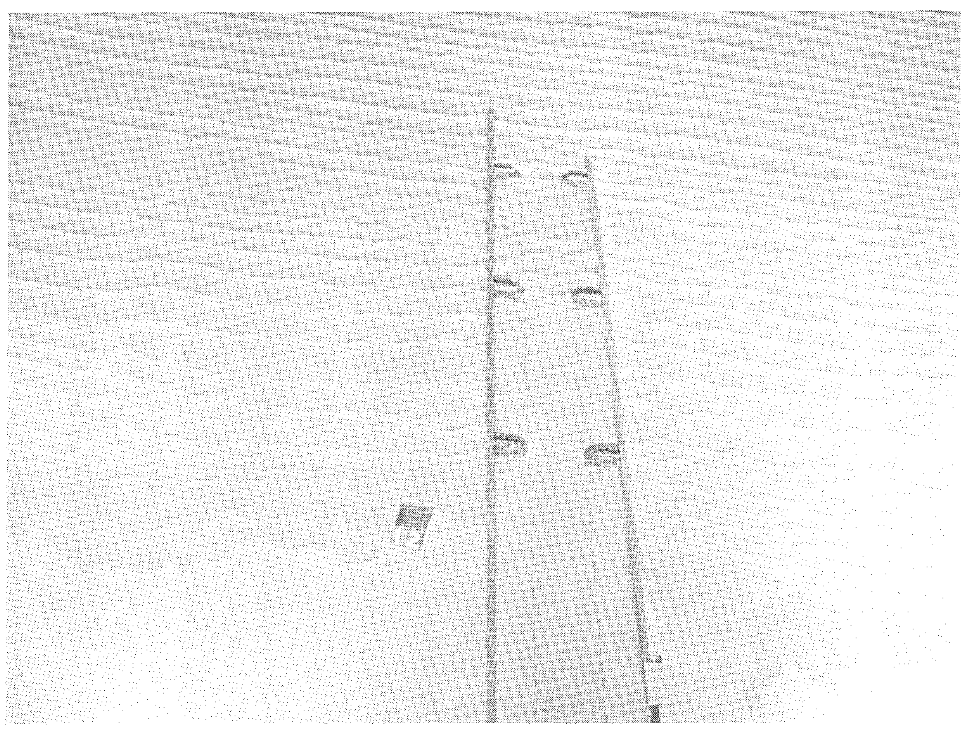


Photo 20. Typical wave patterns for Plan 4; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

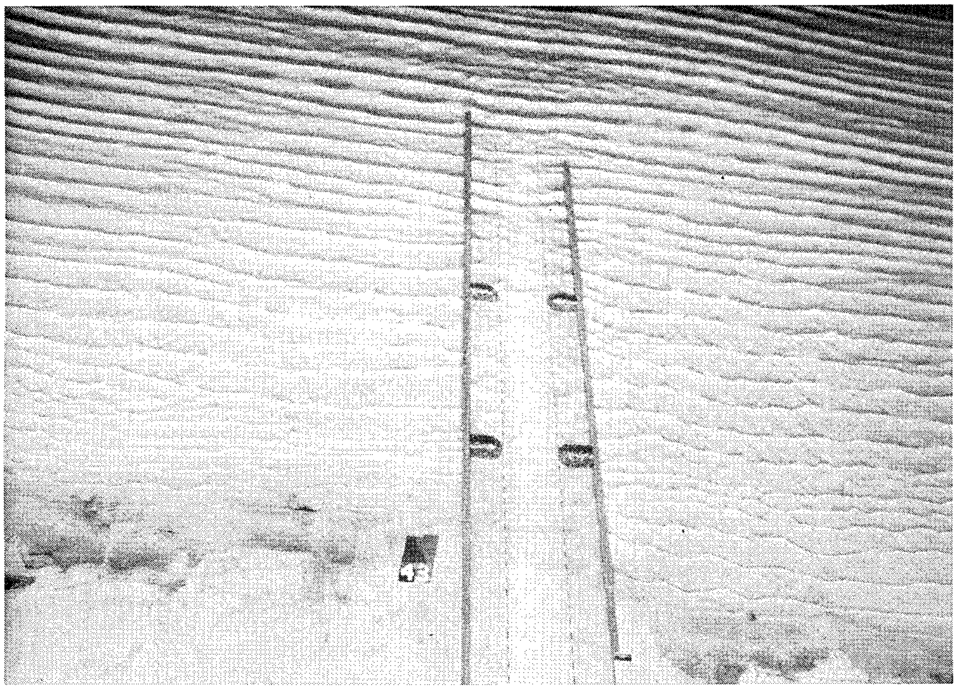


Photo 21. Typical wave patterns for Plan 4A; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

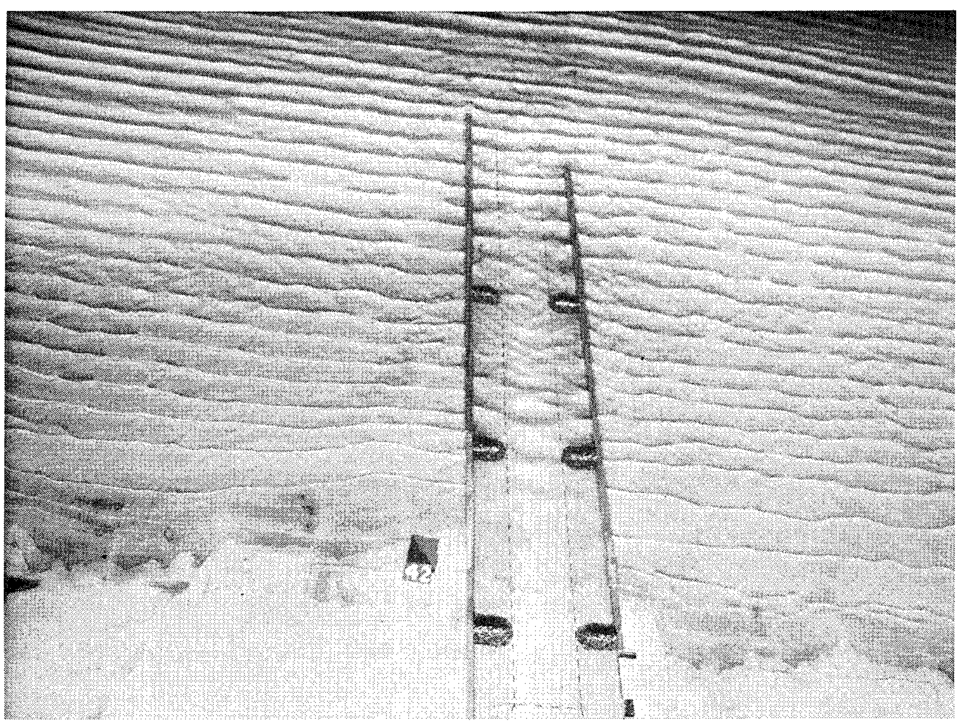


Photo 22. Typical wave patterns for Plan 4B; 6.7-sec, 10.0-ft, 20-year all-season test waves from 34 deg; swl = +4.7 ft LWD

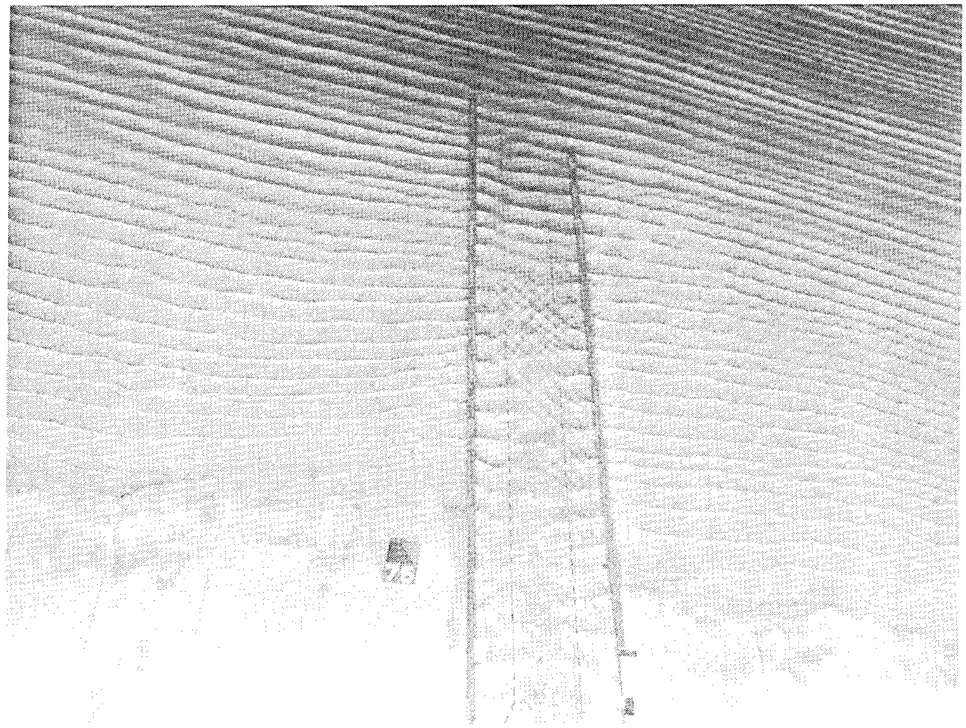


Photo 23. Typical wave patterns for existing conditions; 5.8-sec, 7.1-ft, 5-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

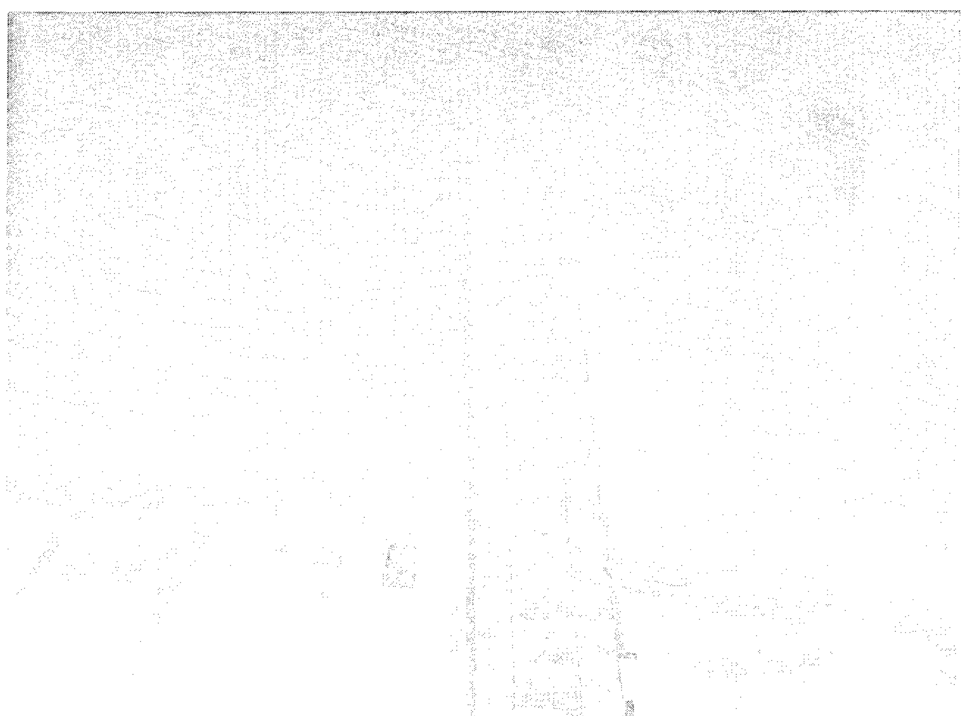


Photo 24. Typical wave patterns for existing conditions; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

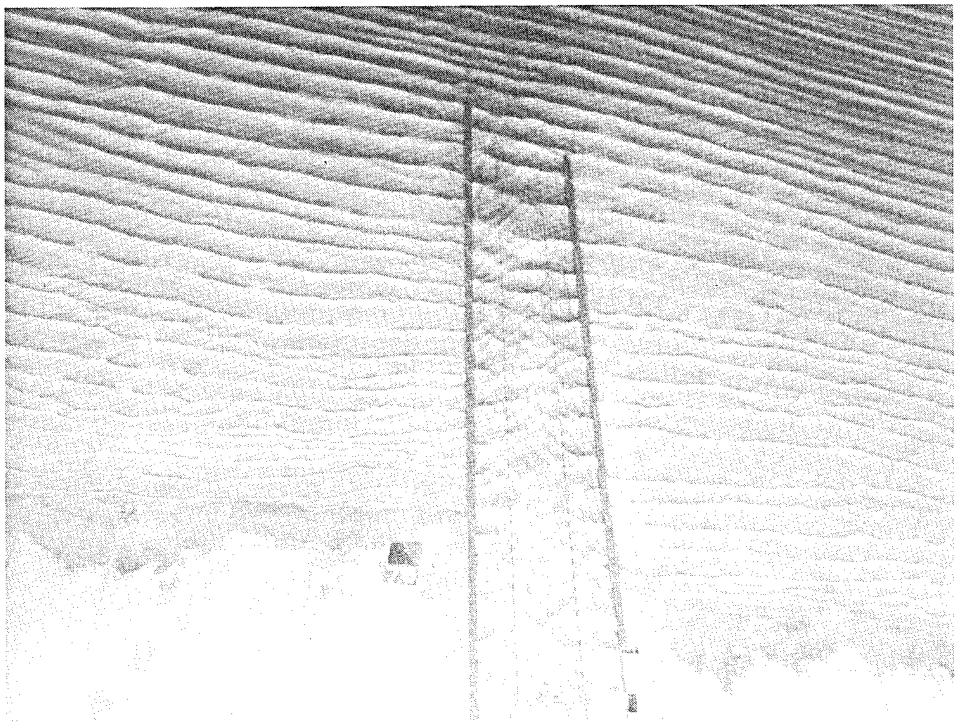


Photo 25. Typical wave patterns for existing conditions; 7.0-sec, 10.6-ft, 50-year all-season test waves from 49 deg; swl = +4.7 ft LWD

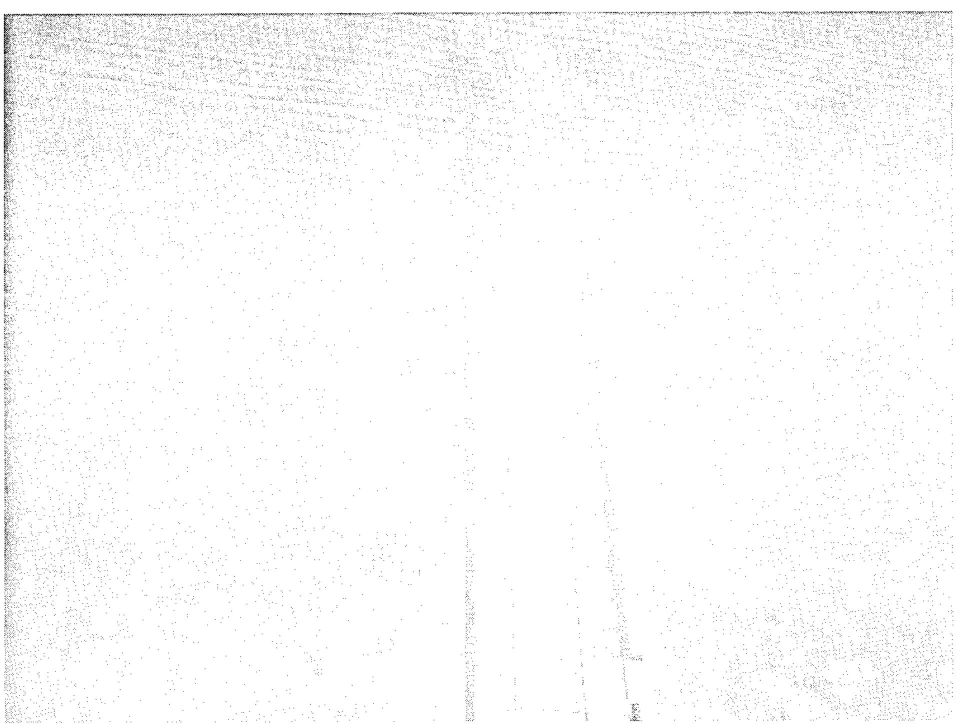


Photo 26. Typical wave patterns for existing conditions; 5.0-sec, 5.2-ft, 5-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

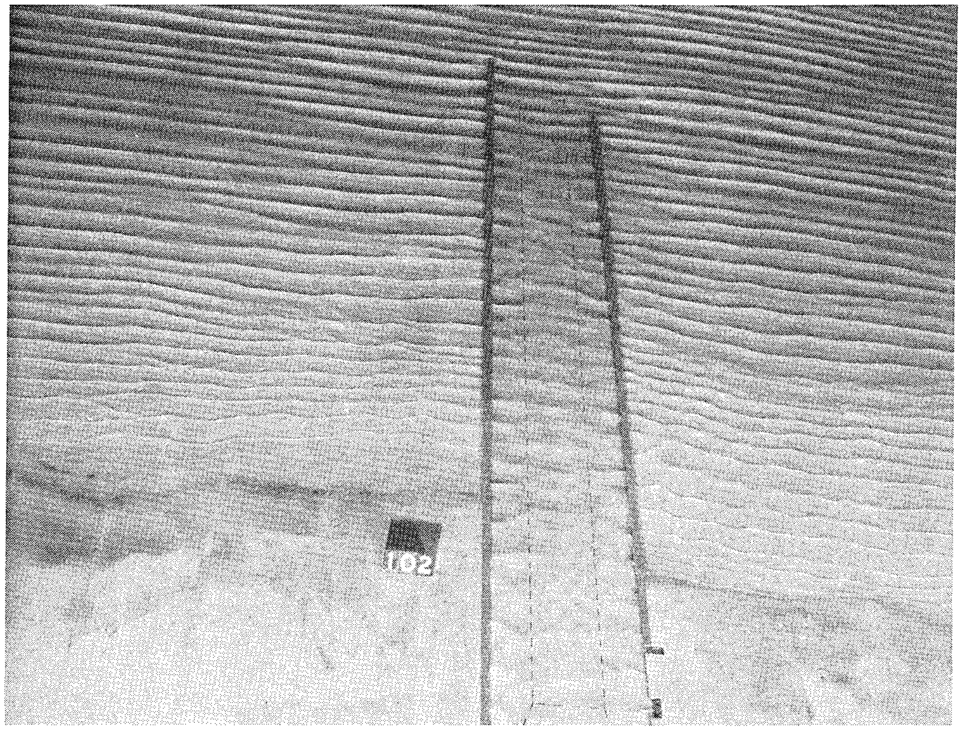


Photo 27. Typical wave patterns for existing conditions; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

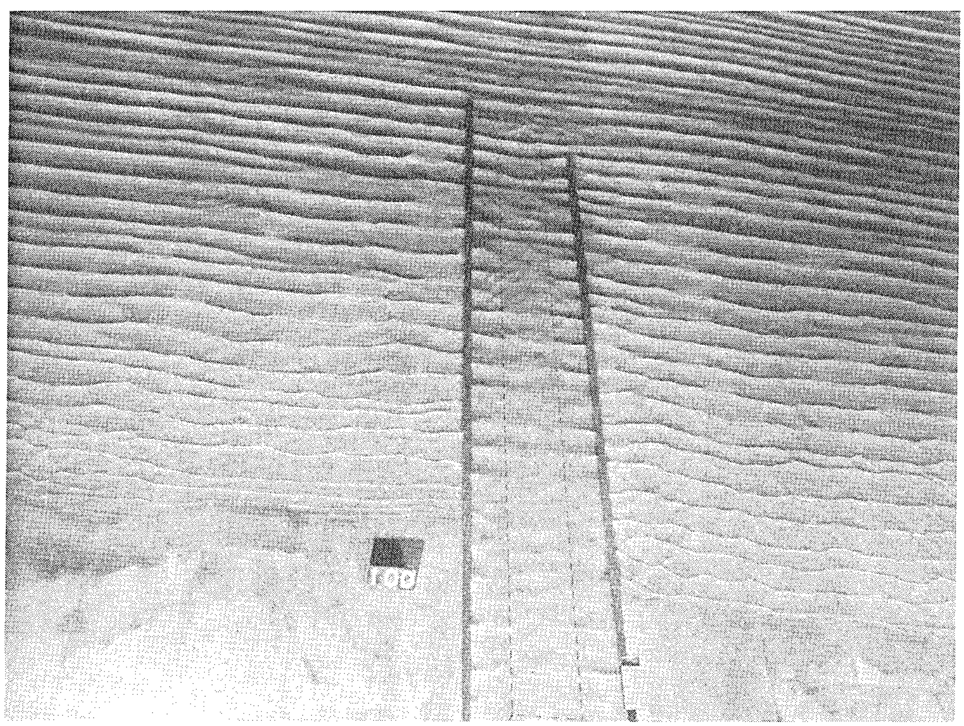


Photo 28. Typical wave patterns for existing conditions; 6.6-sec, 9.7-ft, 50-year all-season test waves from 34 deg; swl = +4.7 ft LWD

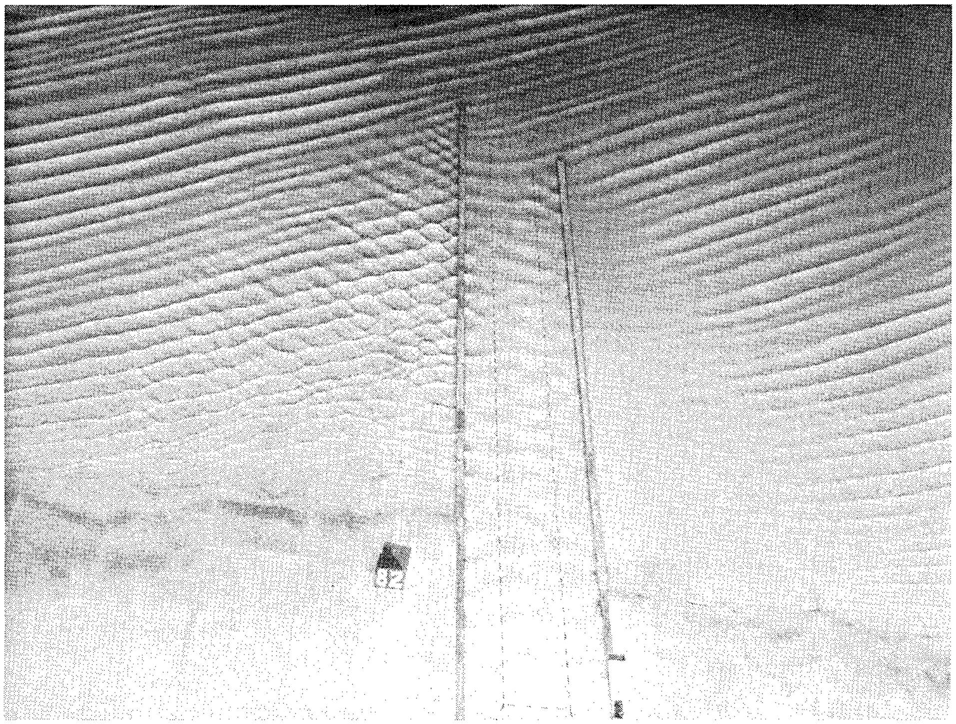


Photo 29. Typical wave patterns for existing conditions; 5.7-sec, 6.0-ft, 5-year navigation season test waves from 354 deg; swl = +2.5 ft LWD

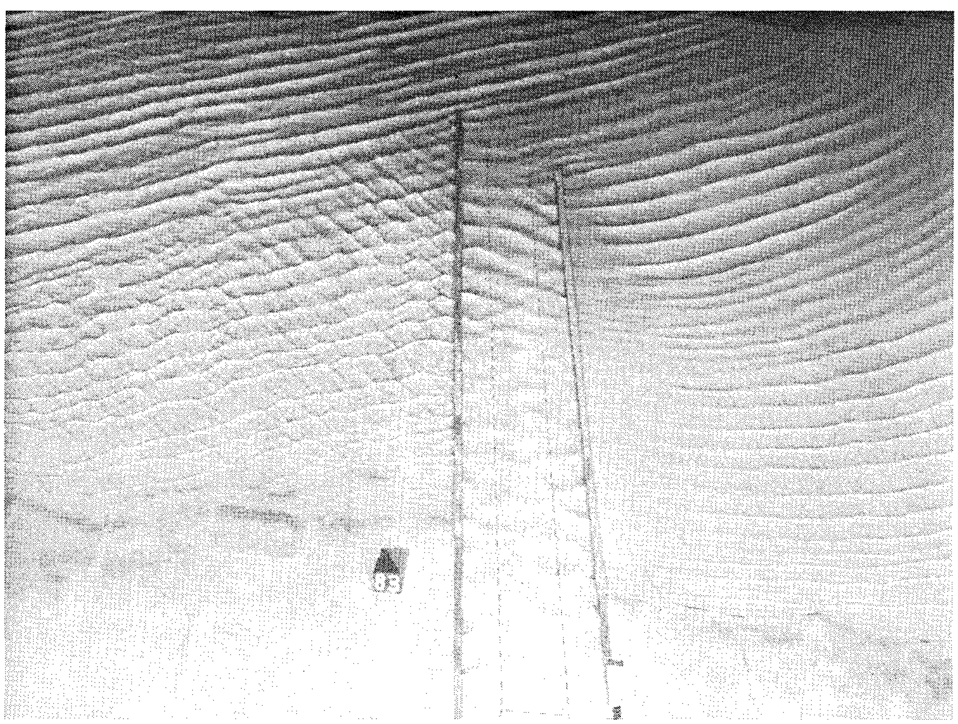


Photo 30. Typical wave patterns for existing conditions; 6.3-sec, 7.4-ft, 20-year navigation season test waves from 354 deg; swl = +2.5 ft LWD

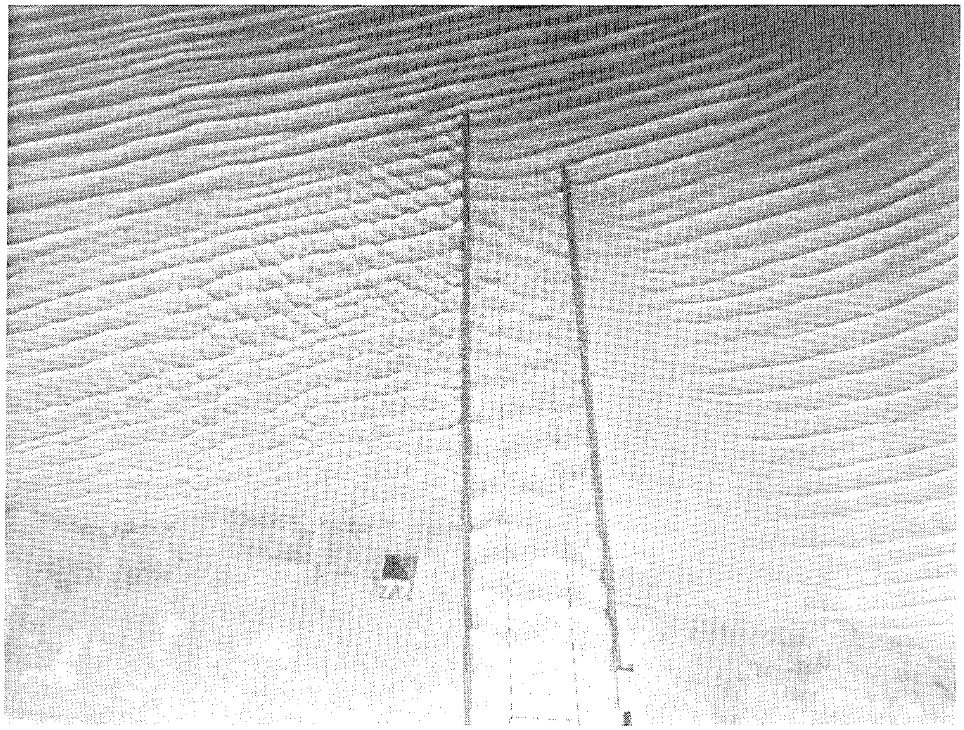


Photo 31. Typical wave patterns for existing conditions; 6.5-sec, 8.0-ft, 50-year all-season test waves from 354 deg; swl = +4.7 ft LWD

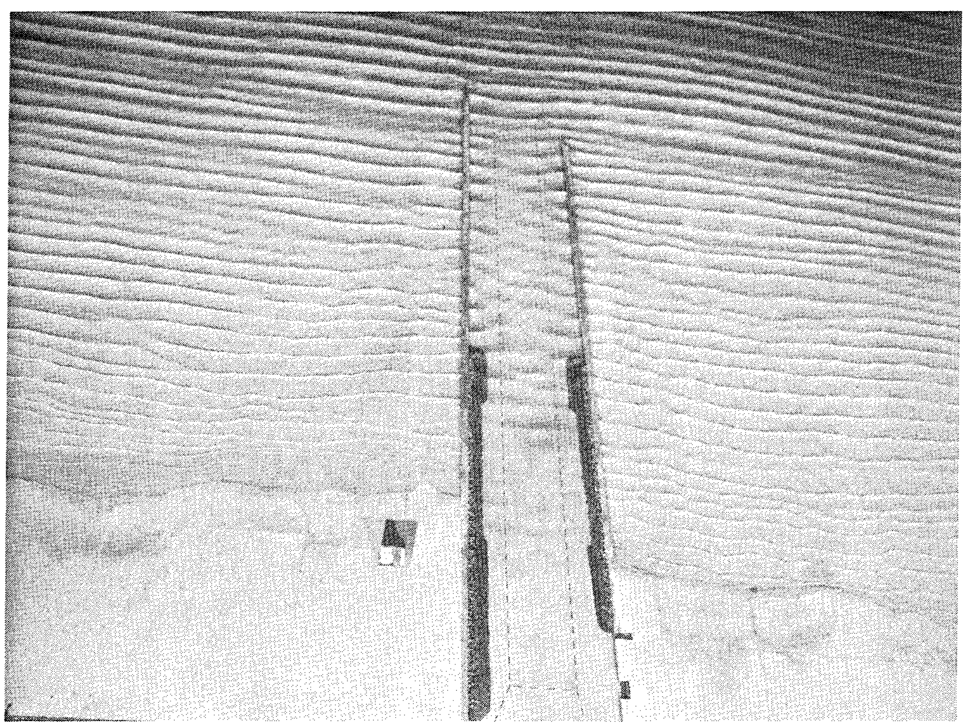


Photo 32. Typical wave patterns for Plan 3L; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

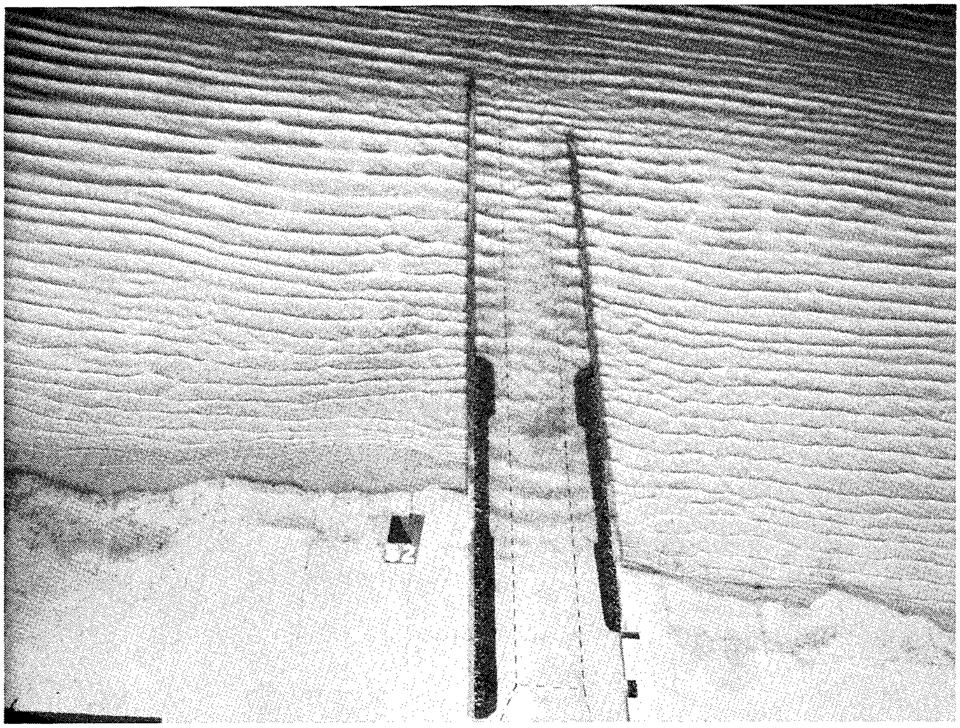


Photo 33. Typical wave patterns for Plan 3M; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

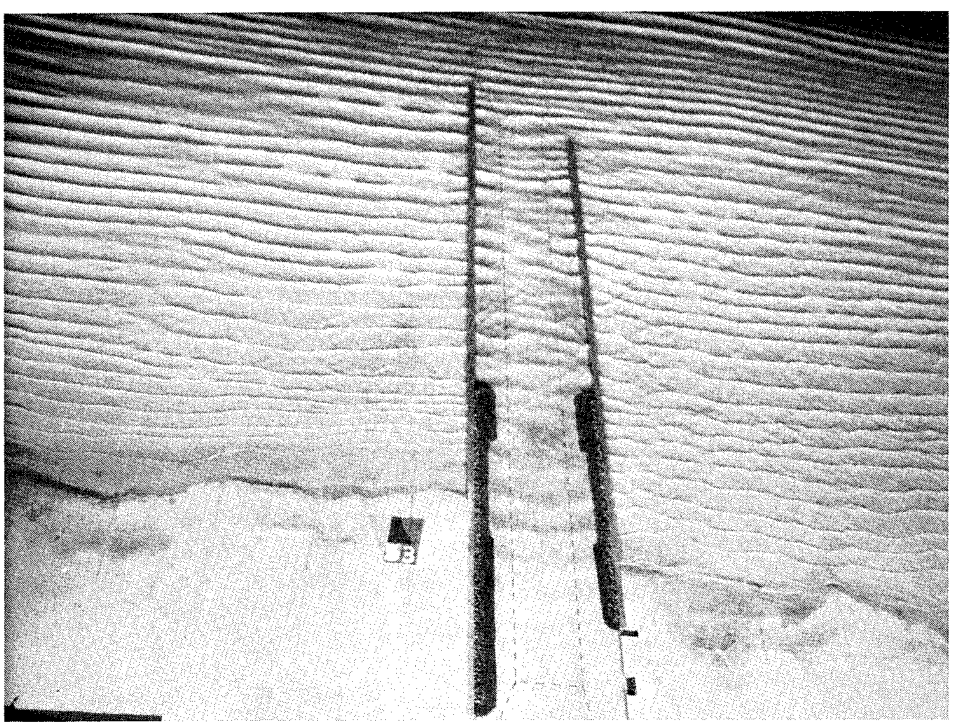


Photo 34. Typical wave patterns for Plan 3N; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

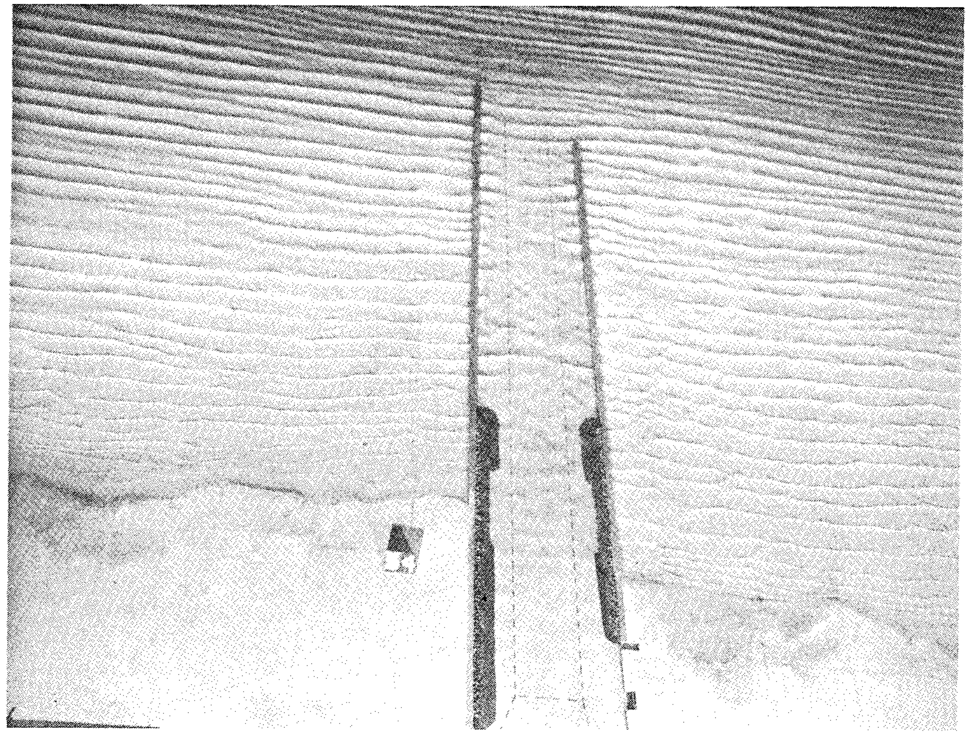


Photo 35. Typical wave patterns for Plan 3O; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

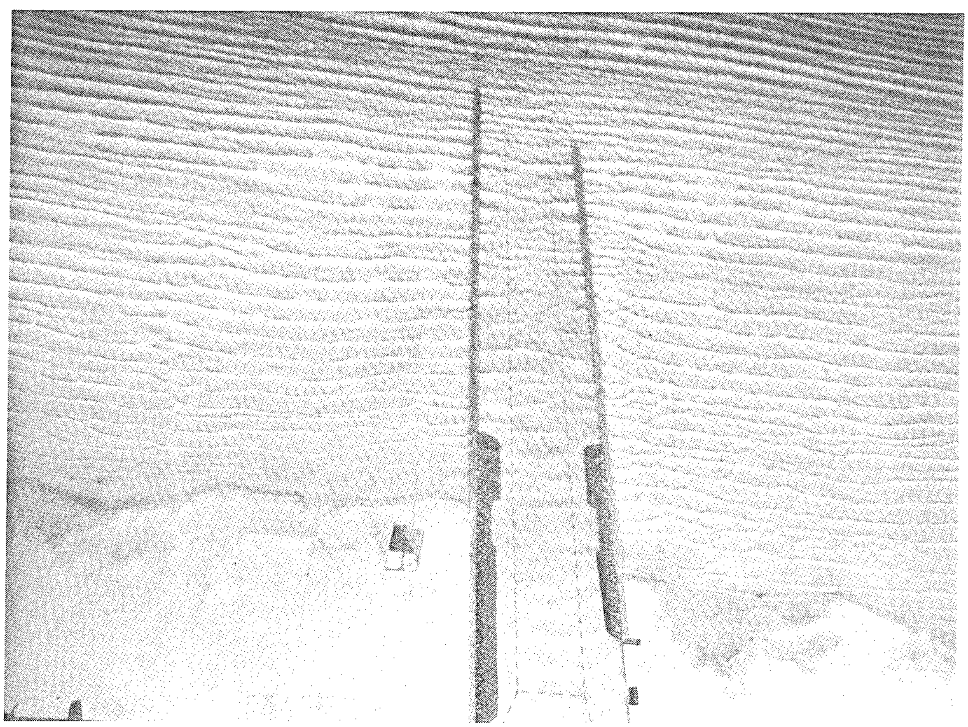


Photo 36. Typical wave patterns for Plan 3P; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

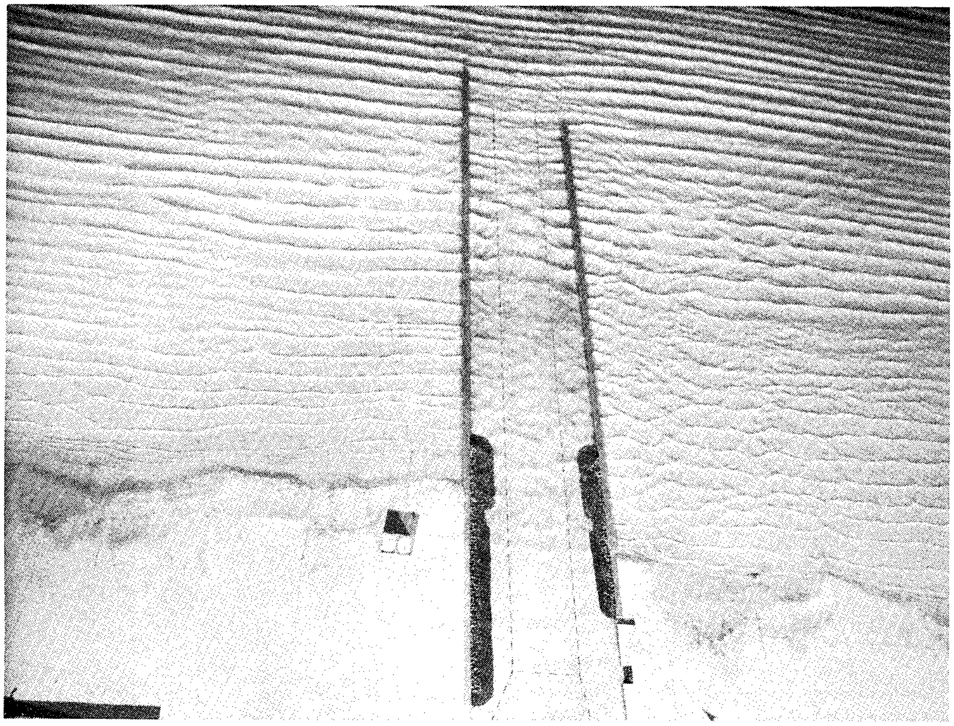


Photo 37. Typical wave patterns for Plan 3Q; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

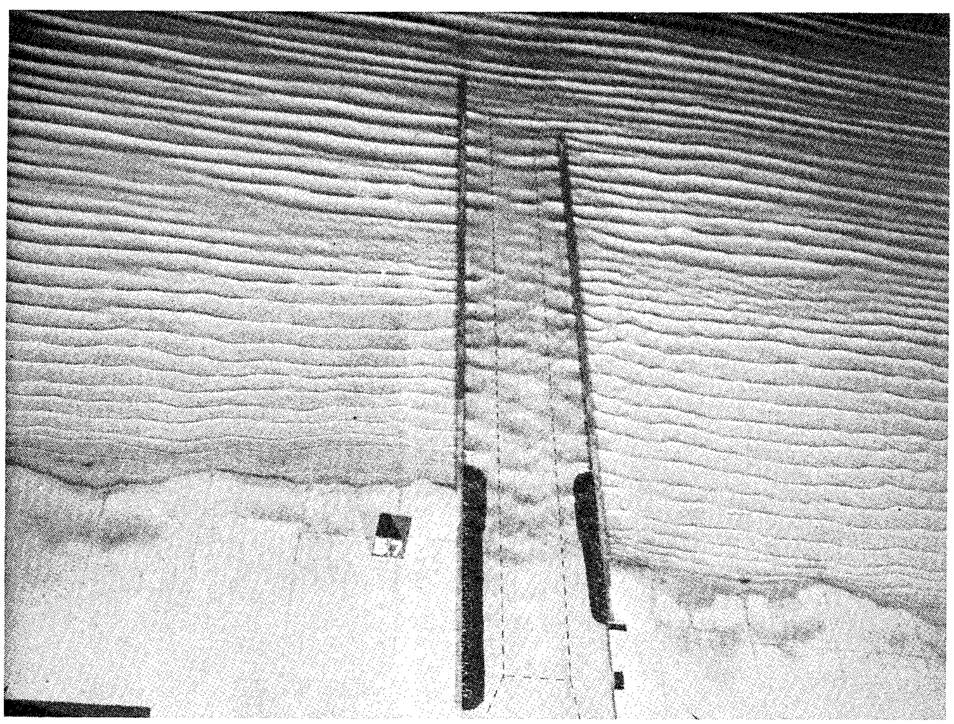


Photo 38. Typical wave patterns for Plan 3R; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

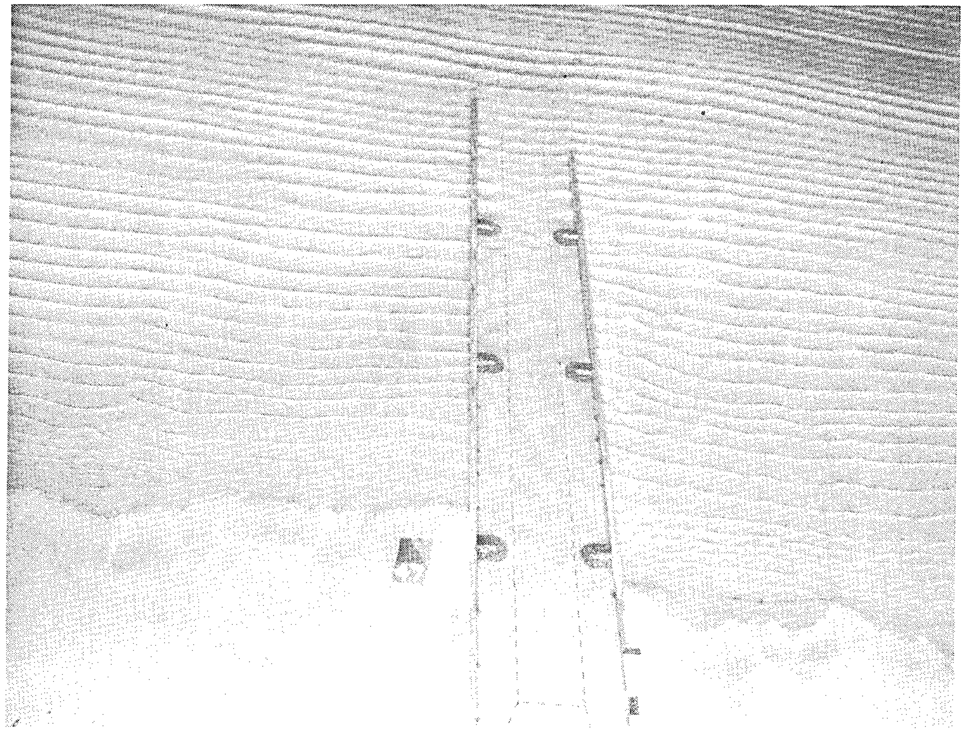


Photo 39. Typical wave patterns for Plan 4C; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

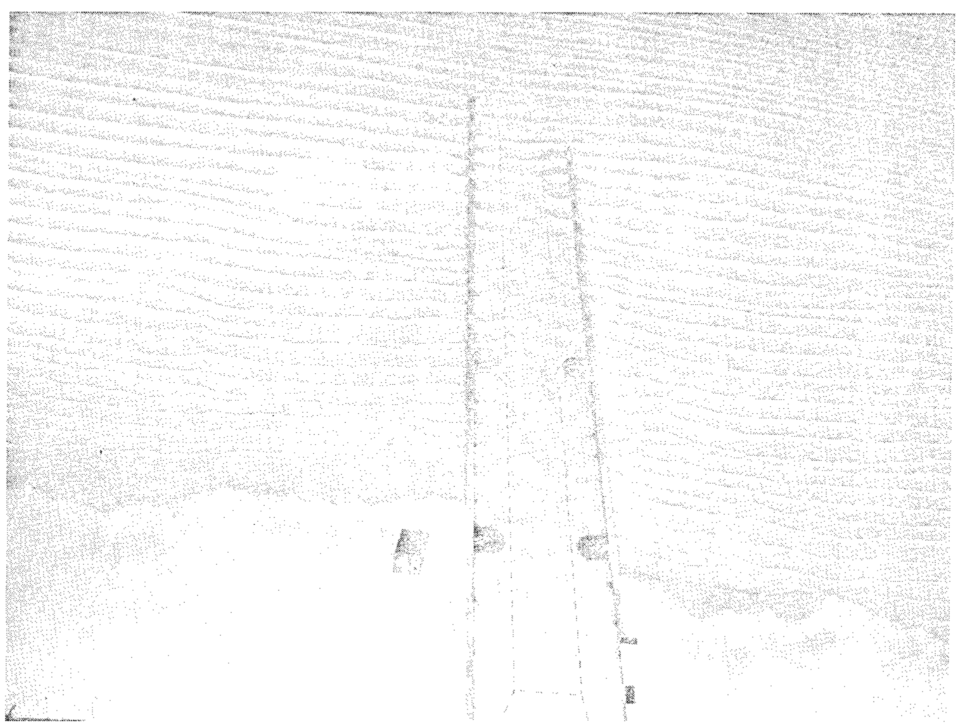


Photo 40. Typical wave patterns for Plan 4D; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

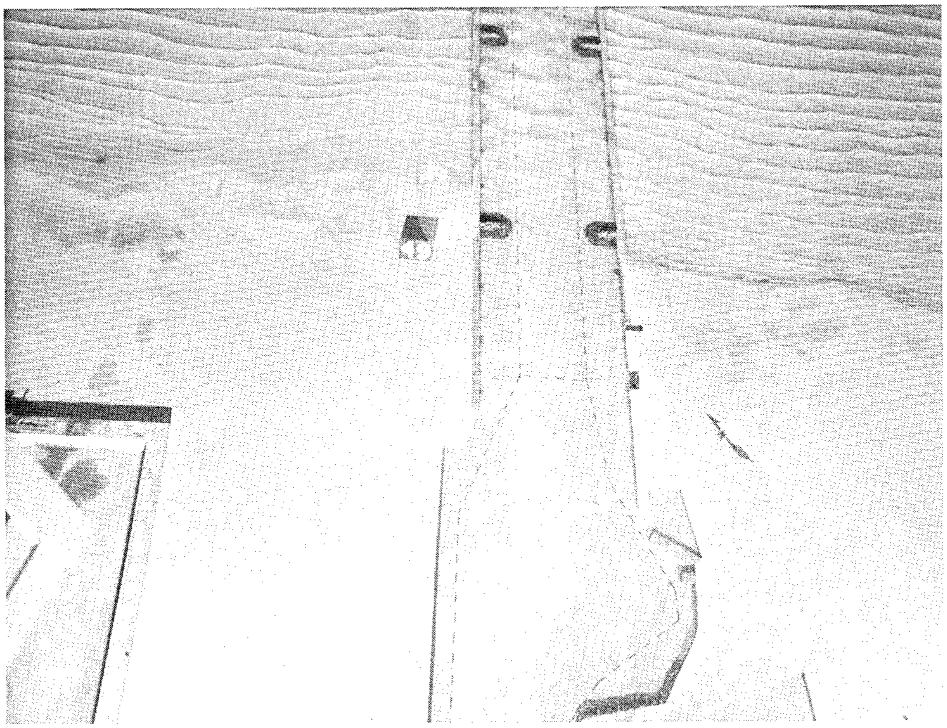


Photo 41. Typical wave patterns for Plan 4E; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

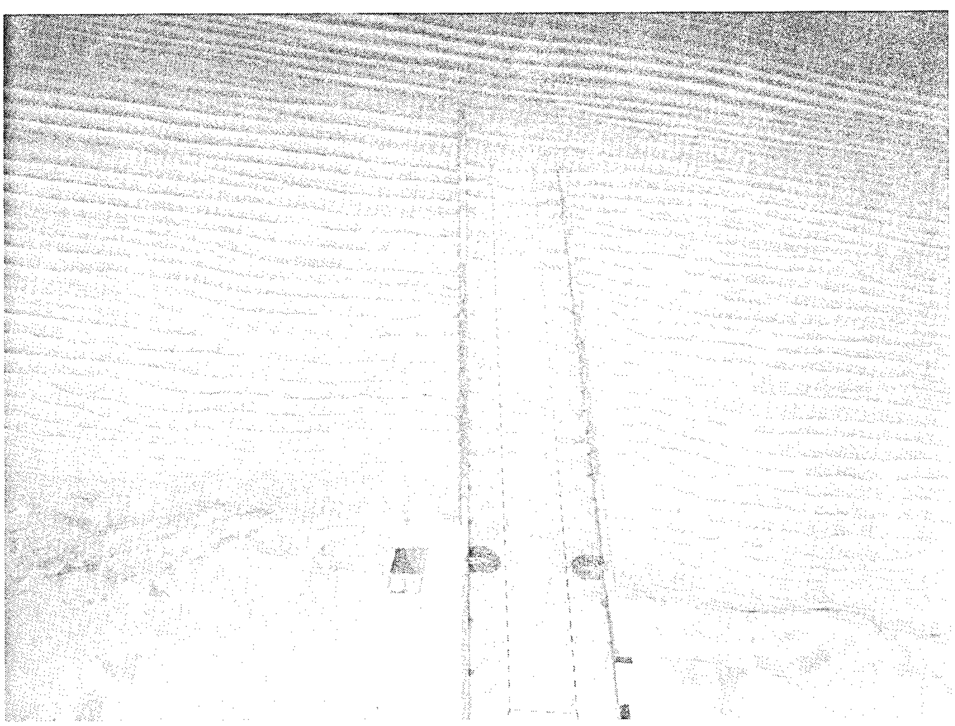


Photo 42. Typical wave patterns for Plan 4F; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

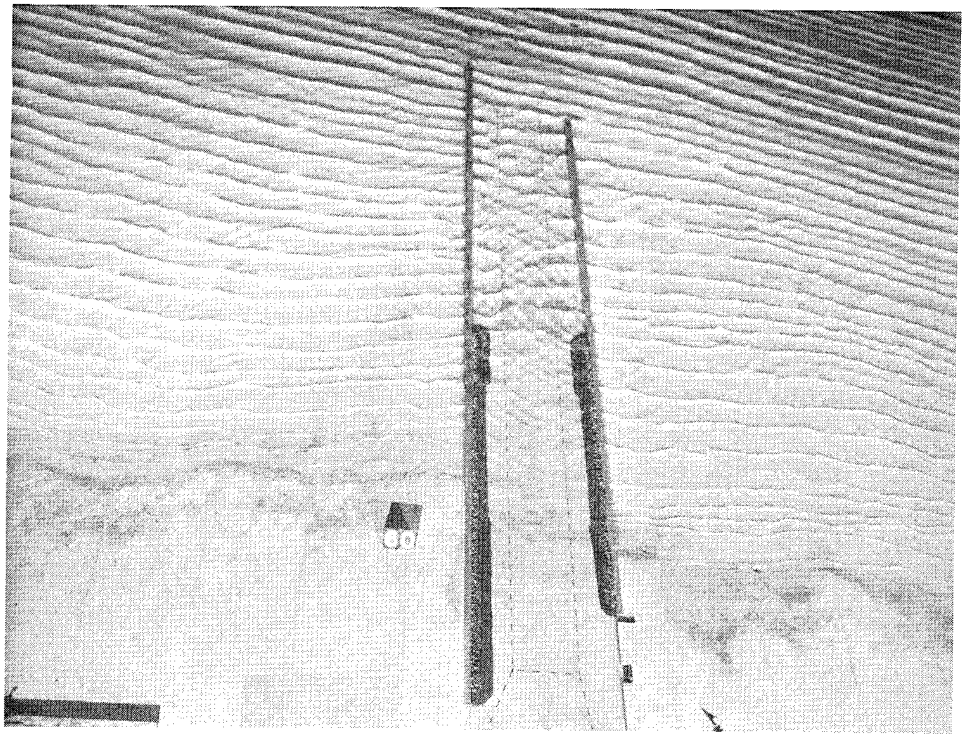


Photo 43. Typical wave patterns for Plan 3L; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

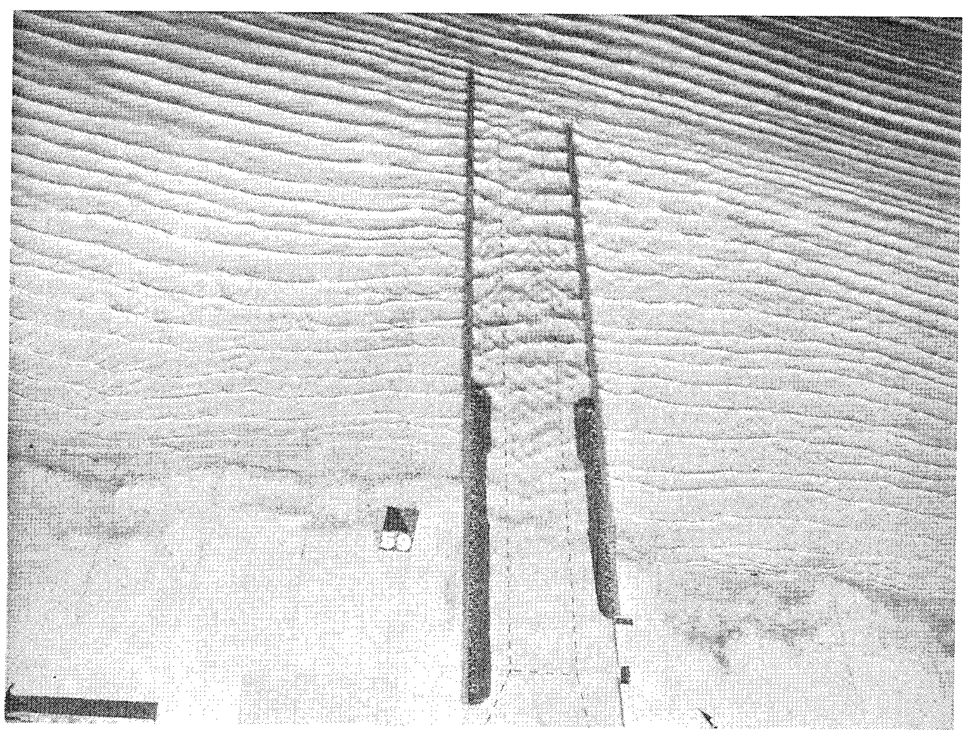


Photo 44. Typical wave patterns for Plan 3O; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

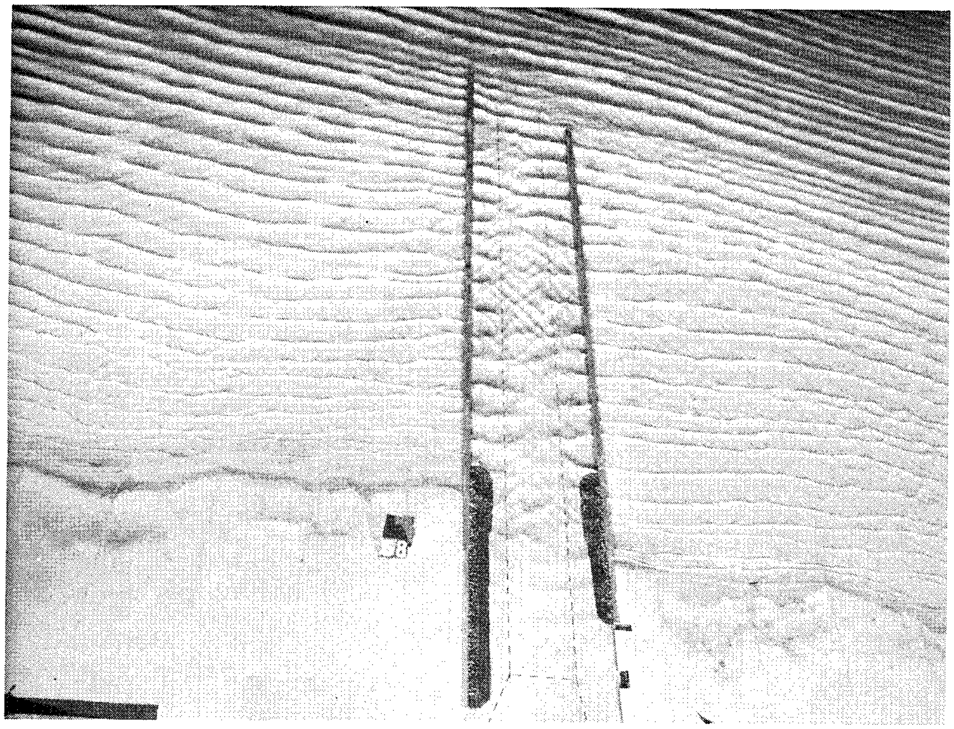


Photo 45. Typical wave patterns for Plan 3R; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

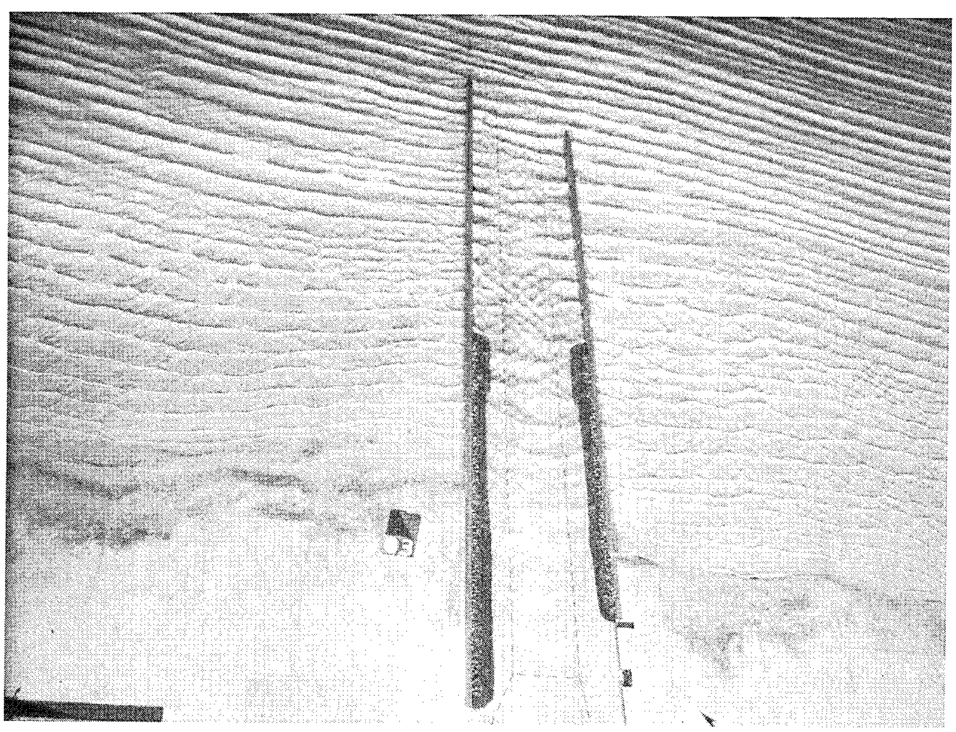


Photo 46. Typical wave patterns for Plan 3S; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

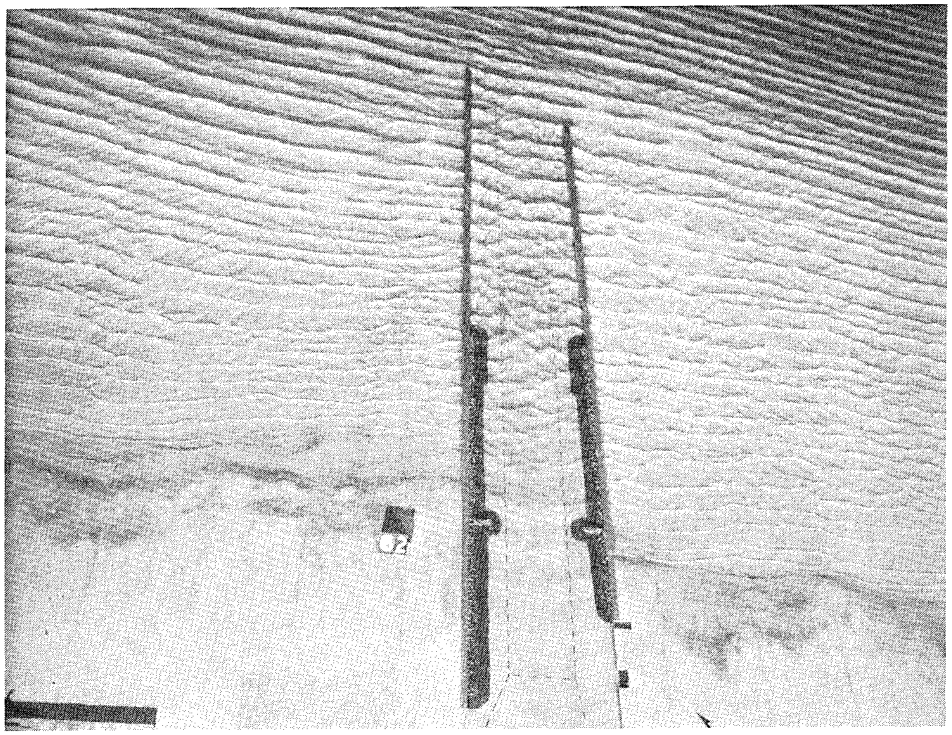


Photo 47. Typical wave patterns for Plan 3T; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

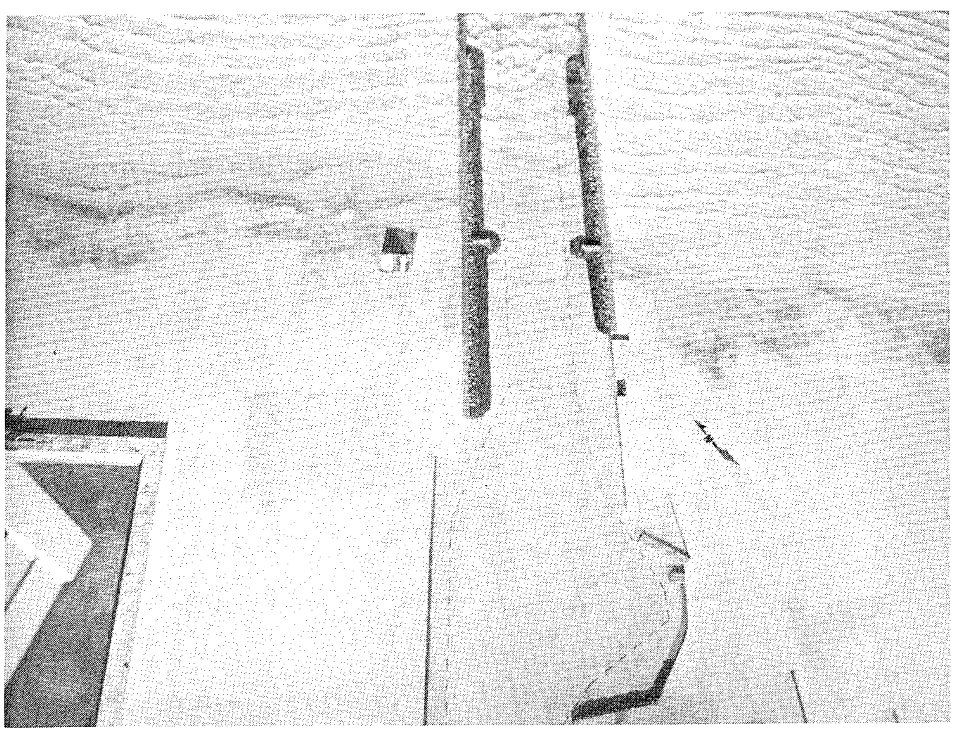


Photo 48. Typical wave patterns for Plan 3U; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

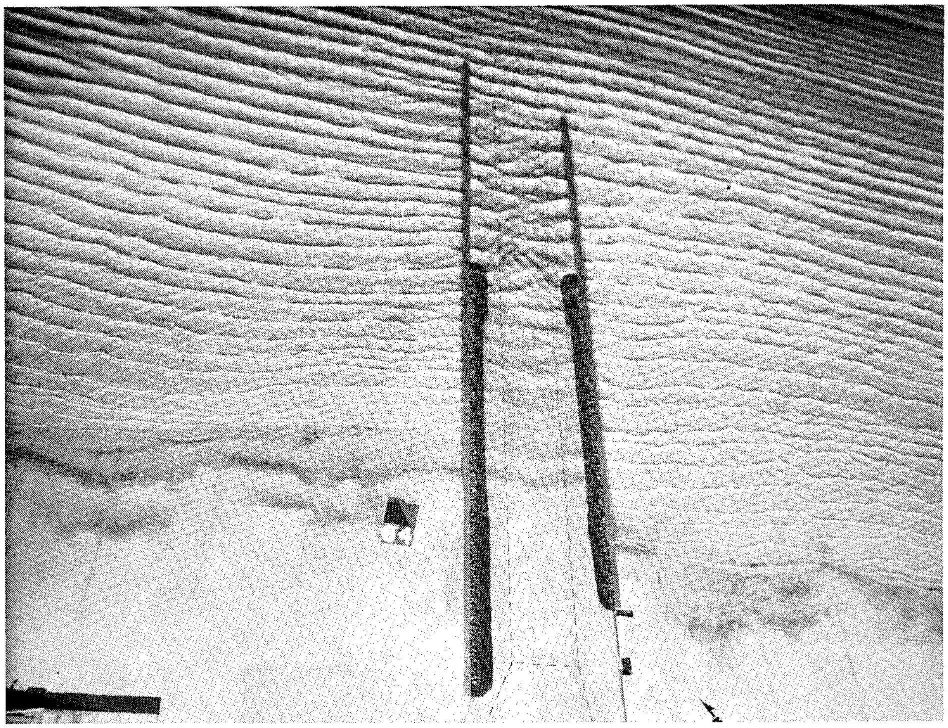


Photo 49. Typical wave patterns for Plan 3V; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

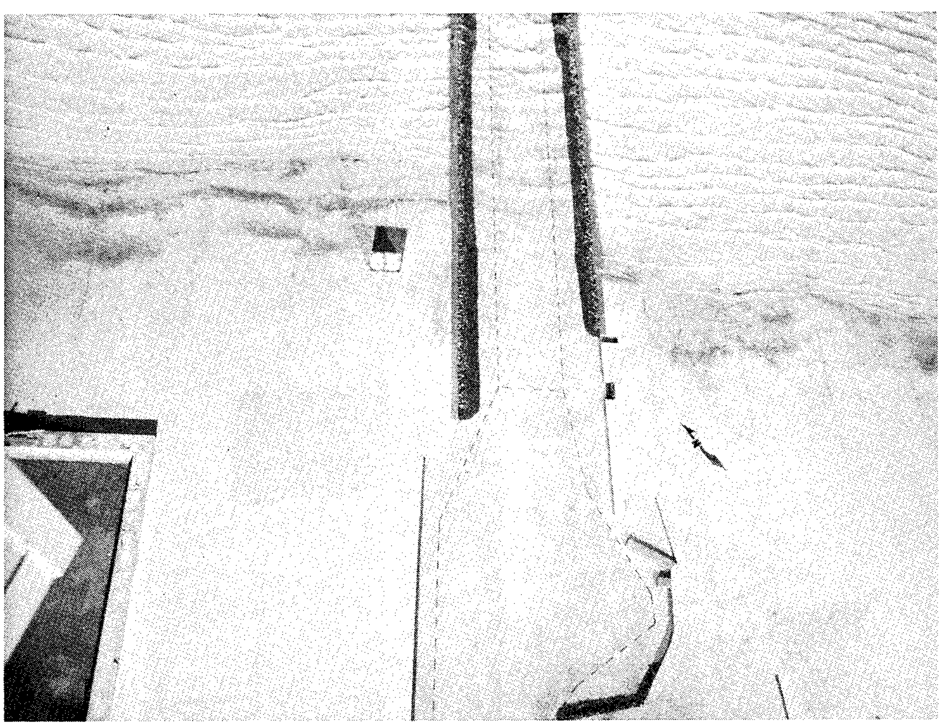


Photo 50. Typical wave patterns for Plan 3W; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

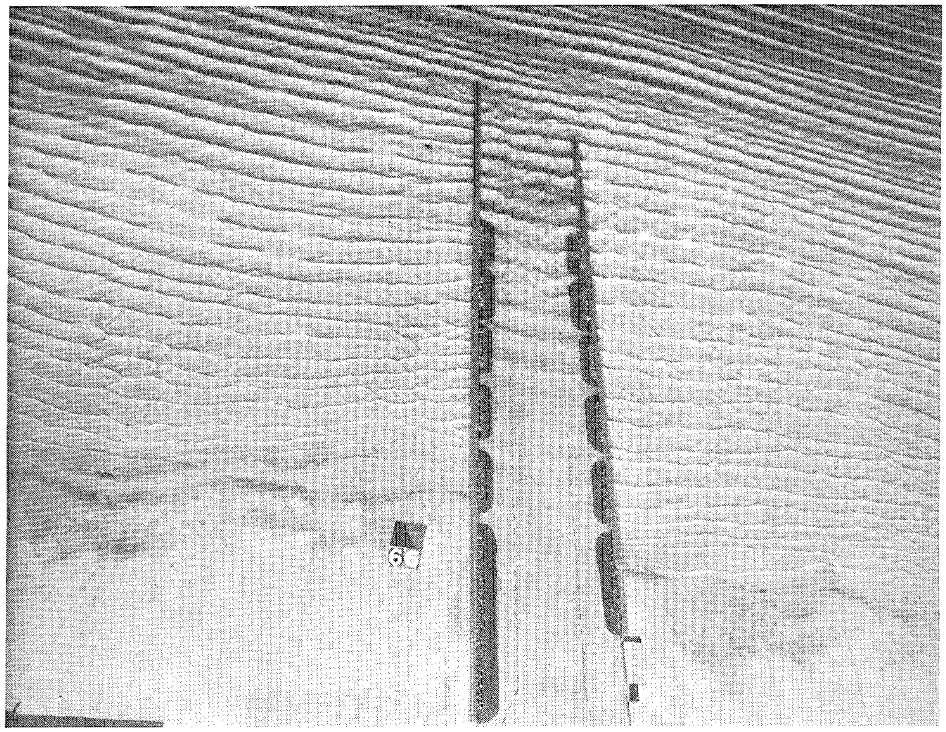


Photo 51. Typical wave patterns for Plan 3X; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

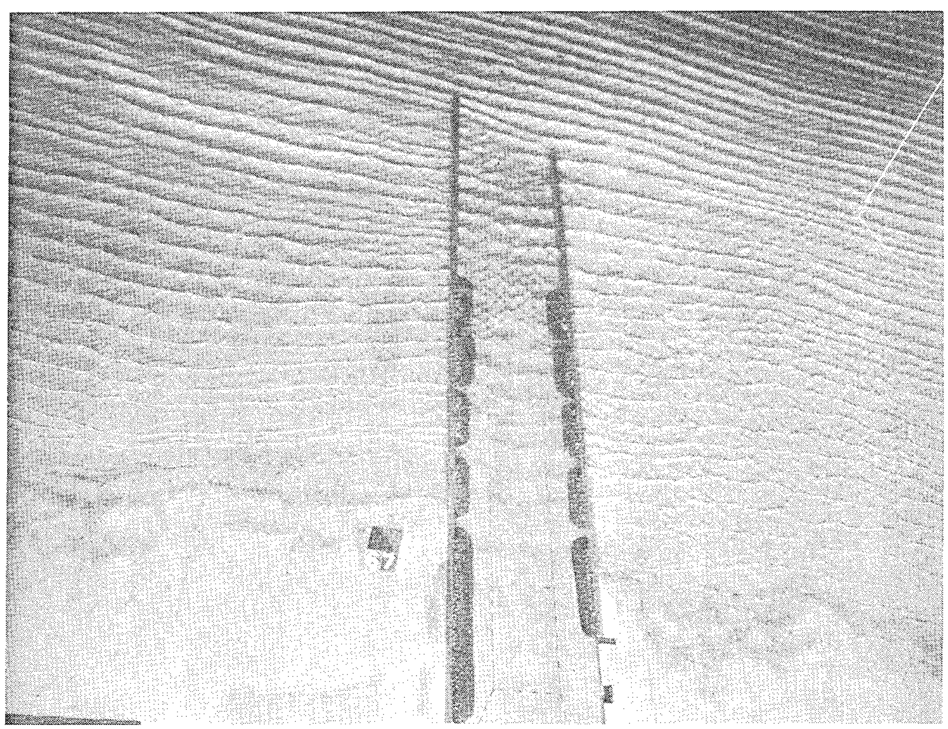


Photo 52. Typical wave patterns for Plan 3Y; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

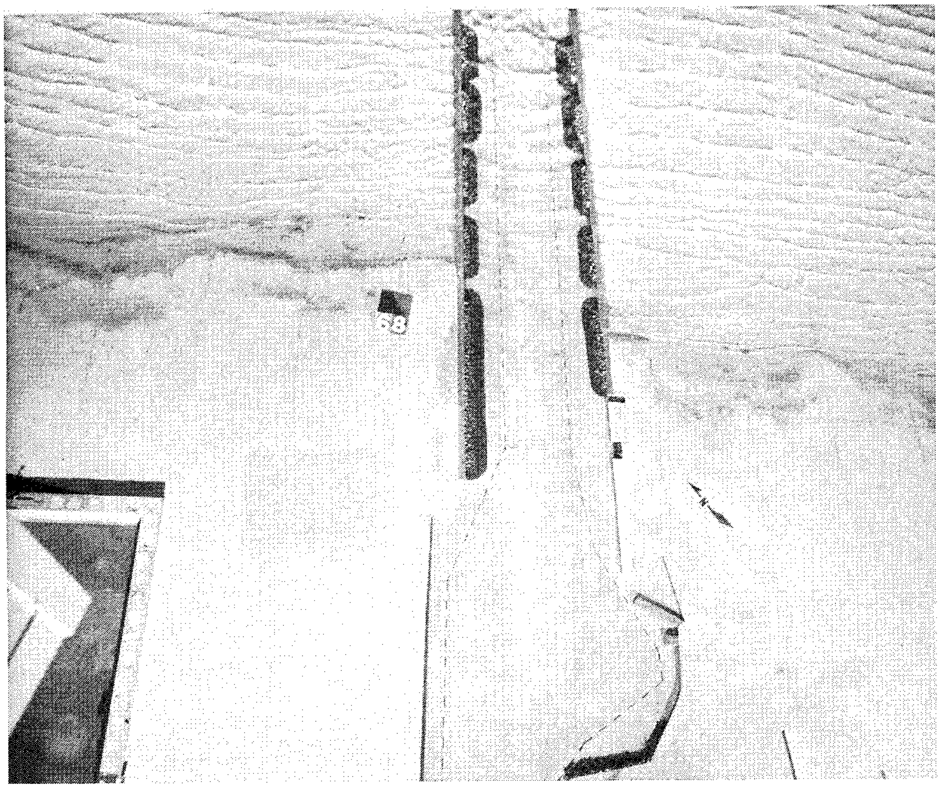


Photo 53. Typical wave patterns for Plan 3Z; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

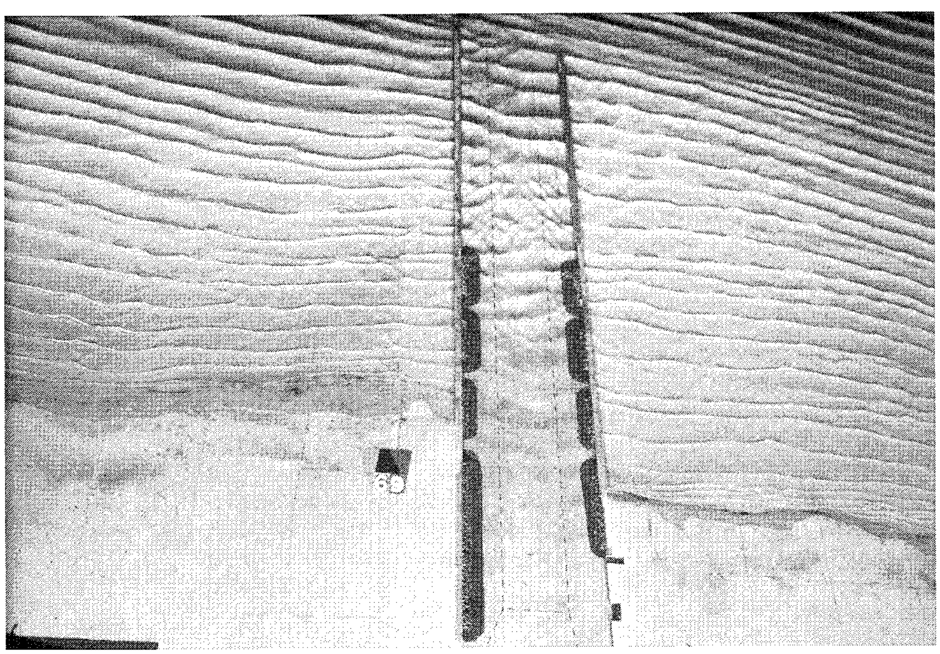


Photo 54. Typical wave patterns for Plan 3AA; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

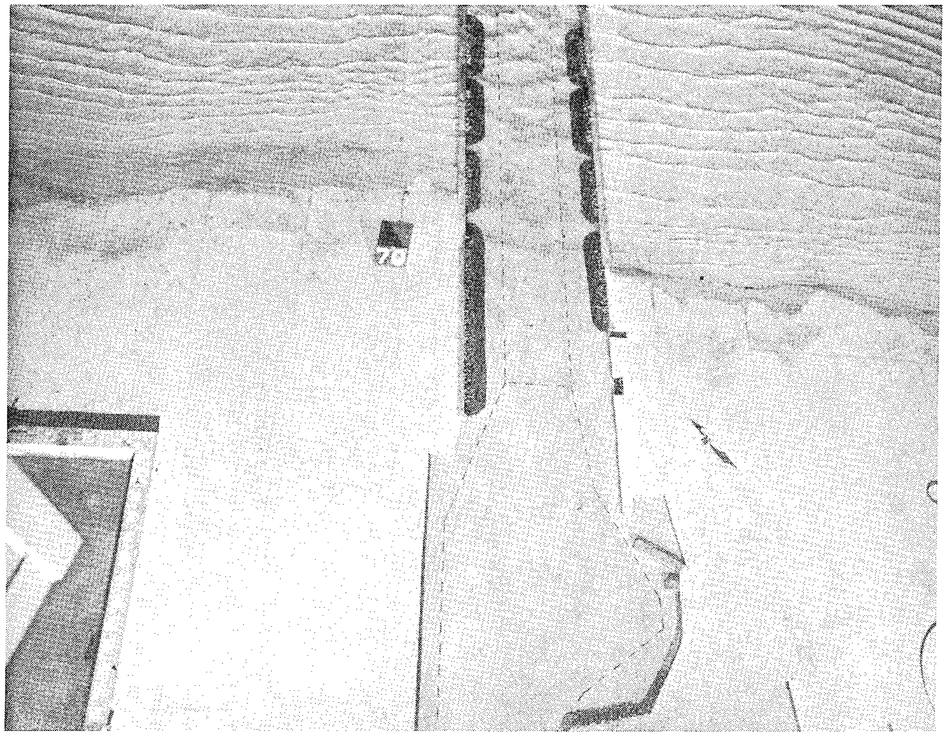


Photo 55. Typical wave patterns for Plan 3BB; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

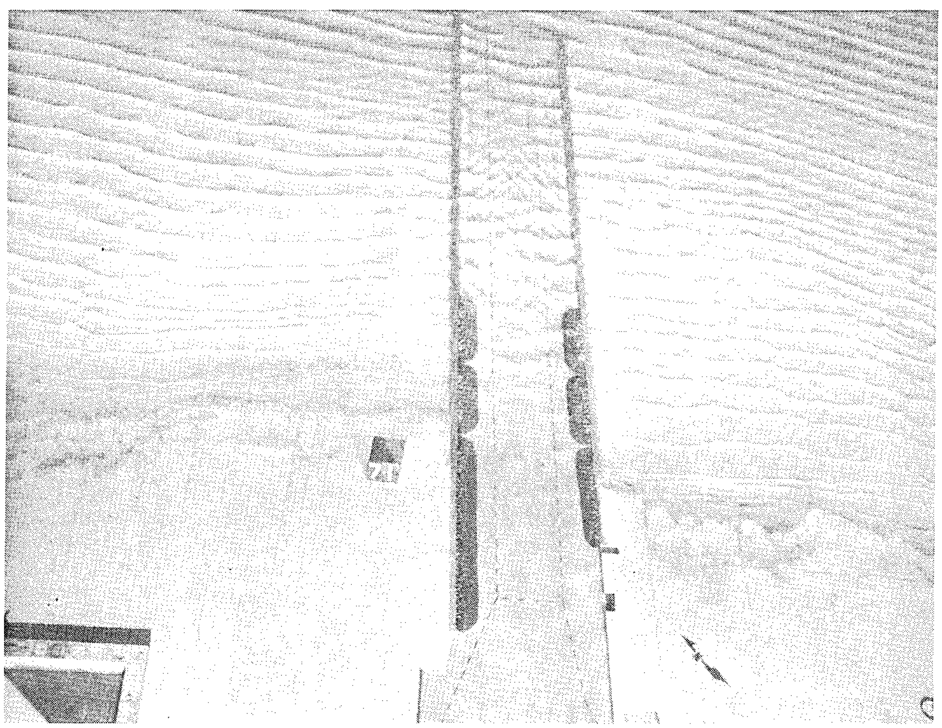


Photo 56. Typical wave patterns for Plan 3CC; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

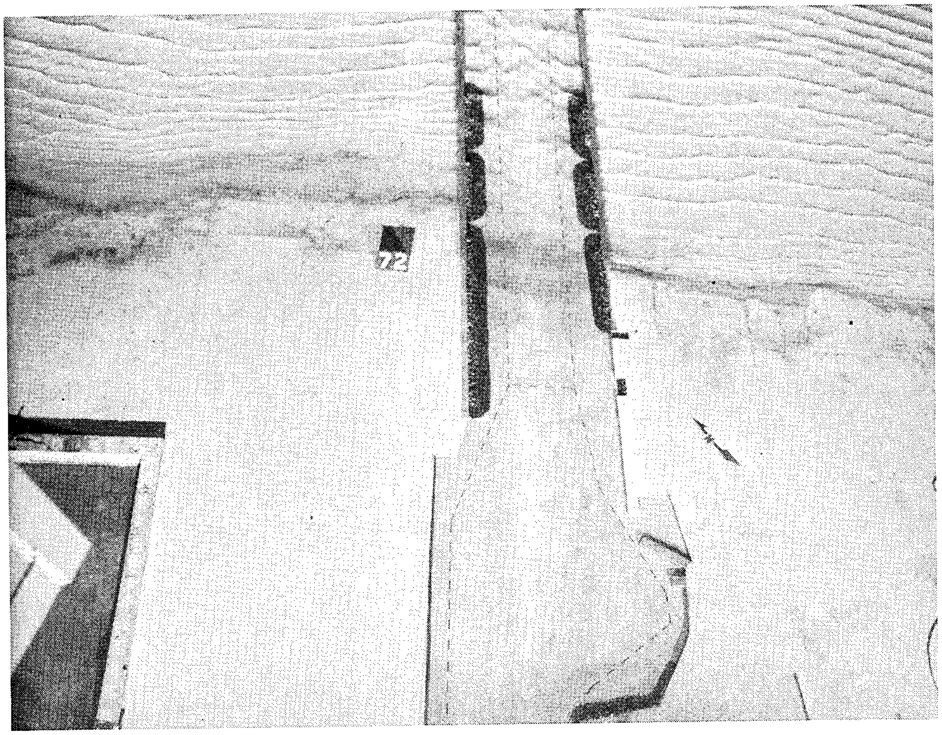


Photo 57. Typical wave patterns for Plan 3DD; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

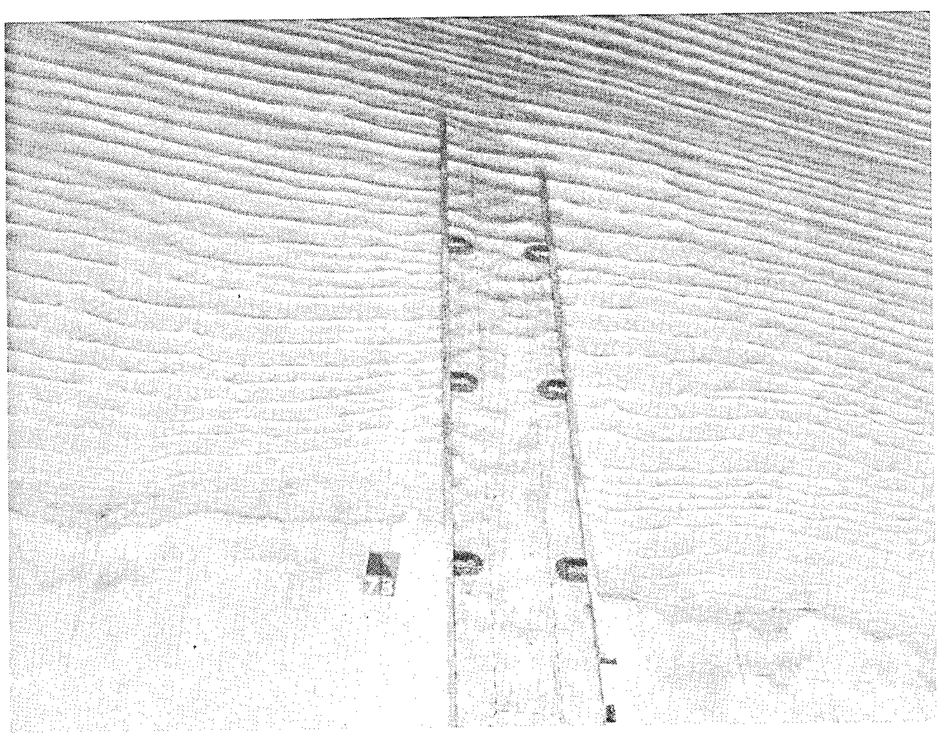


Photo 58. Typical wave patterns for Plan 4C; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

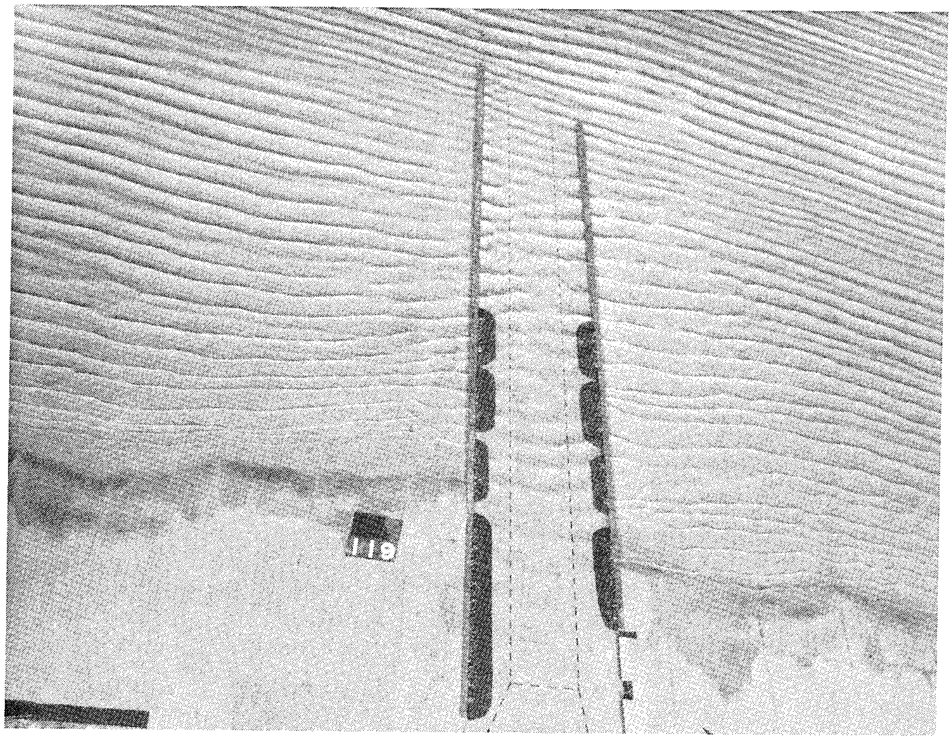


Photo 59. Typical wave patterns for Plan 3BB; 5.8-sec, 7.1-ft, 5-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

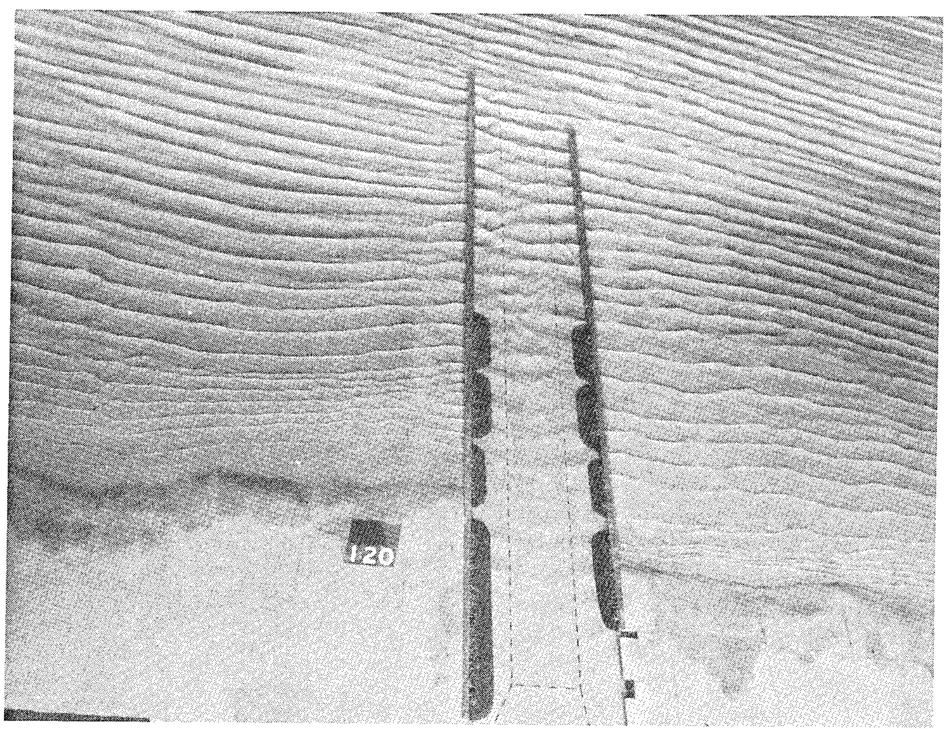


Photo 60. Typical wave patterns for Plan 3BB; 6.4-sec, 9.1-ft, 20-year navigation season test waves from 49 deg; swl = +2.5 ft LWD

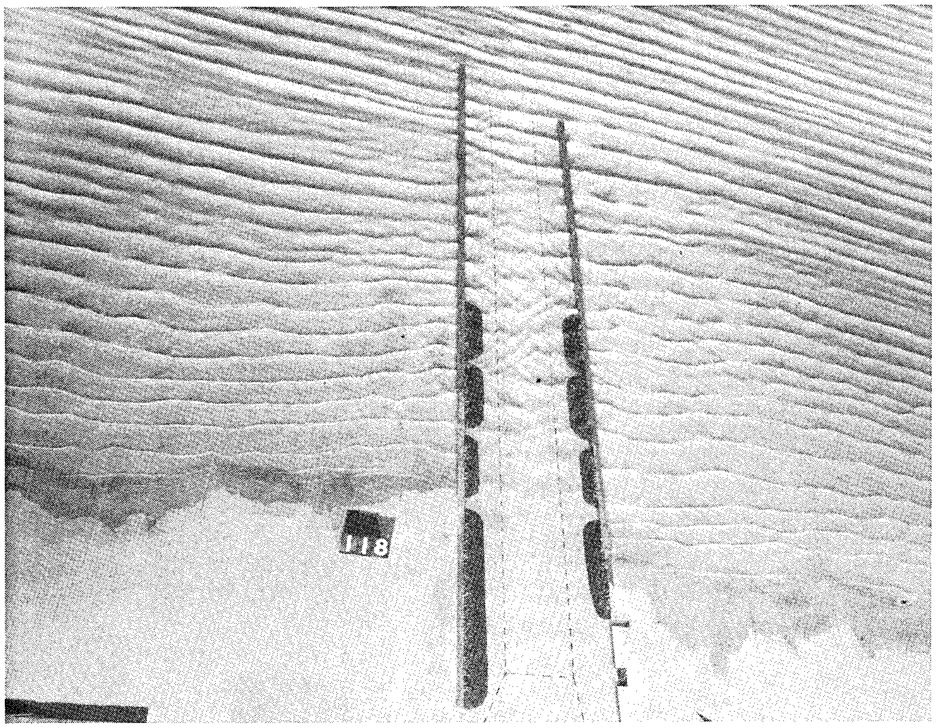


Photo 61. Typical wave patterns for Plan 3BB; 7.0-sec, 10.6-ft, 50-year all-season test waves from 49 deg; swl = +4.7 ft LWD

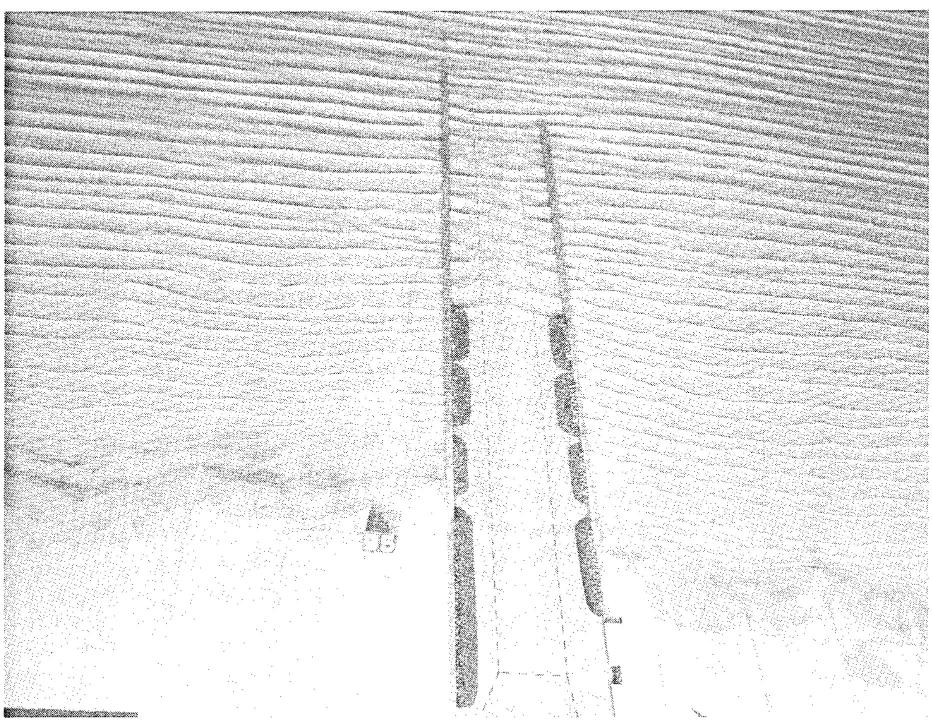


Photo 62. Typical wave patterns for Plan 3BB; 5.8-sec, 7.2-ft, 20-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

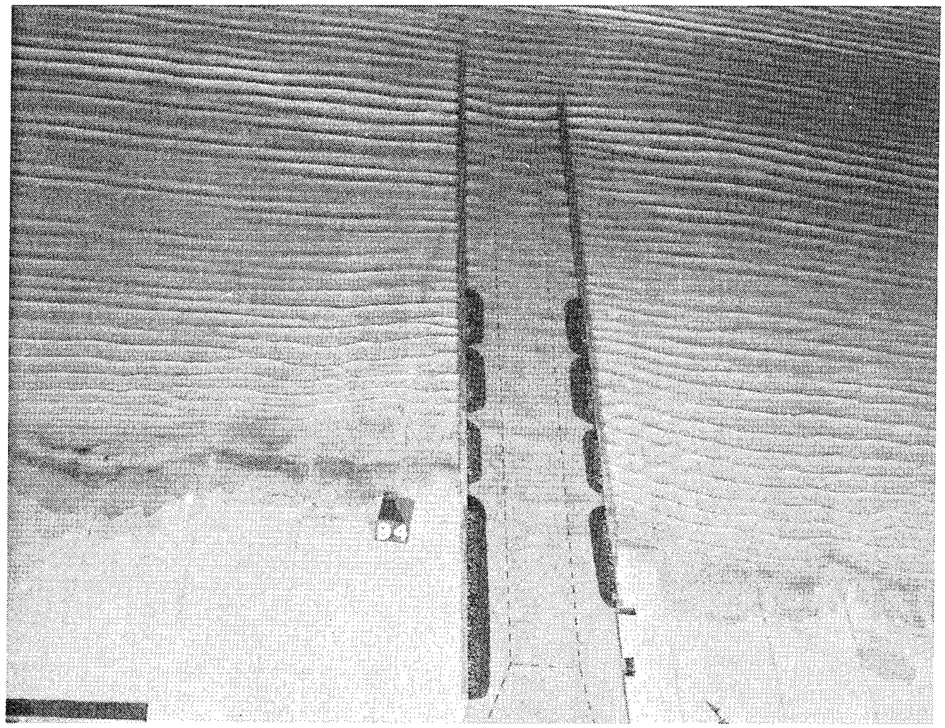


Photo 63. Typical wave patterns for Plan 3BB; 5.0-sec, 5.2-ft, 5-year navigation season test waves from 34 deg; swl = +2.5 ft LWD

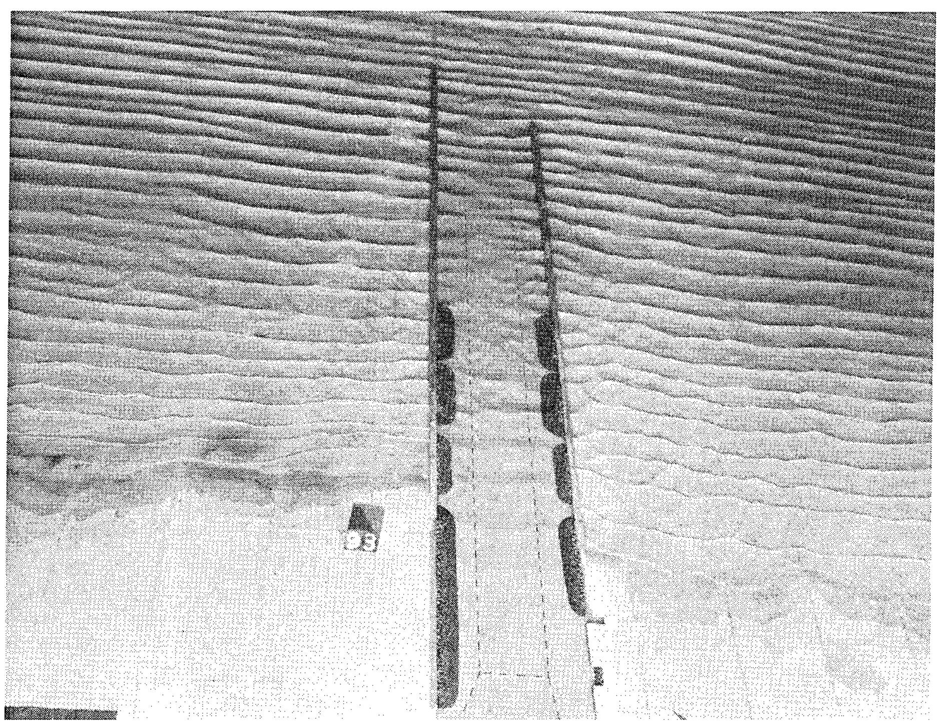


Photo 64. Typical wave patterns for Plan 3BB; 6.6-sec, 9.7-ft, 50-year all-season test waves from 34 deg; swl = +4.7 ft LWD

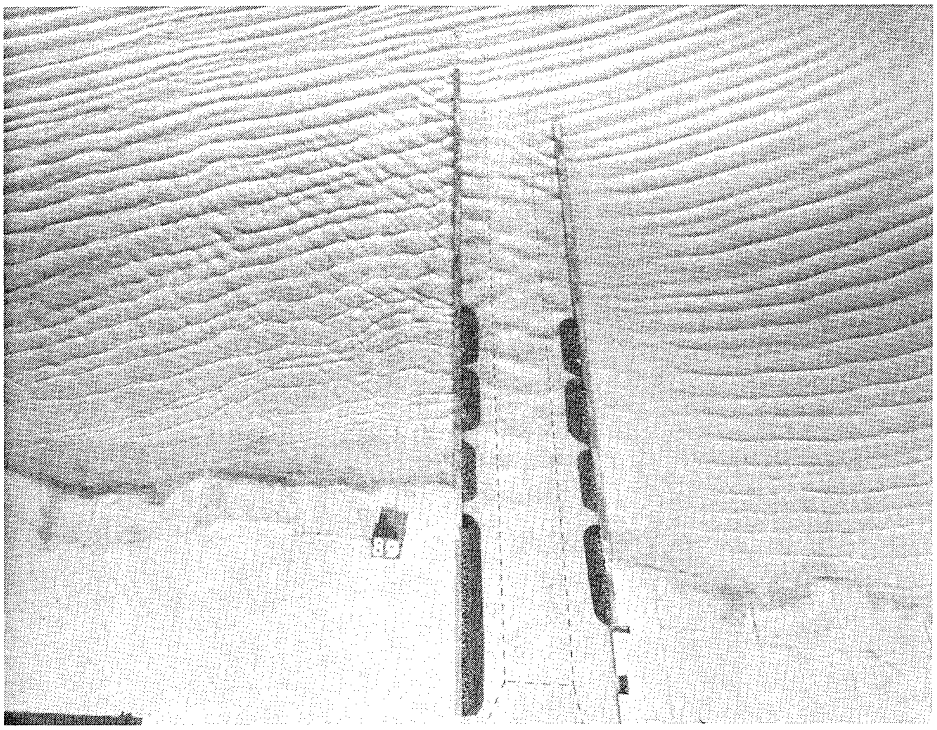


Photo 65. Typical wave patterns for Plan 3BB; 6.3-sec, 7.4-ft, 20-year navigation season test waves from 354 deg; swl = +2.5 ft LWD

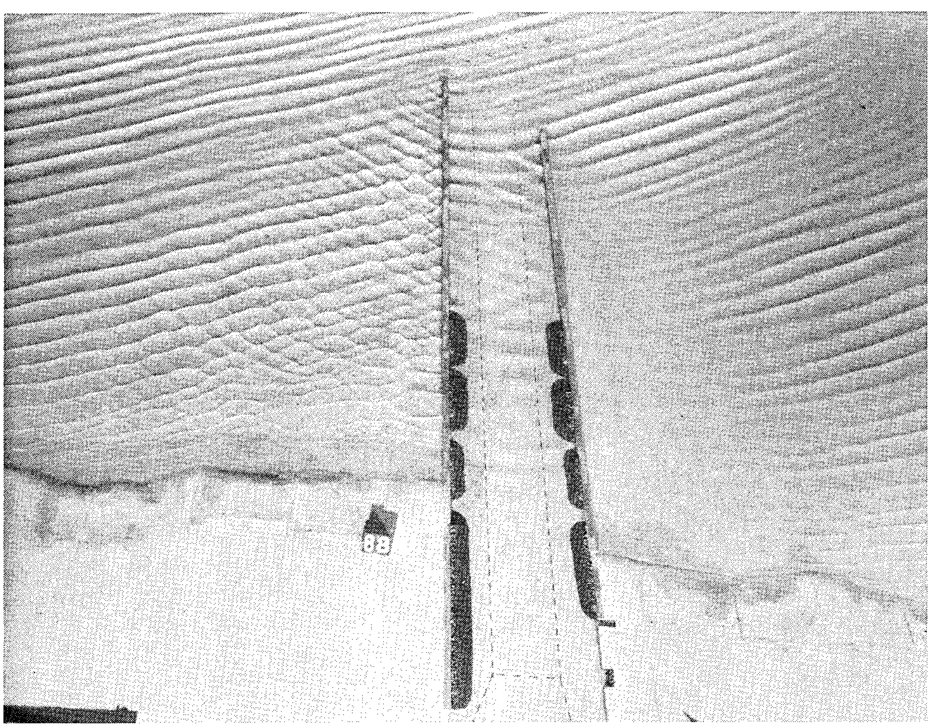


Photo 66. Typical wave patterns for Plan 3BB; 5.7-sec, 6.0-ft, 5-year navigation season test waves from 354 deg; swl = +2.5 ft LWD

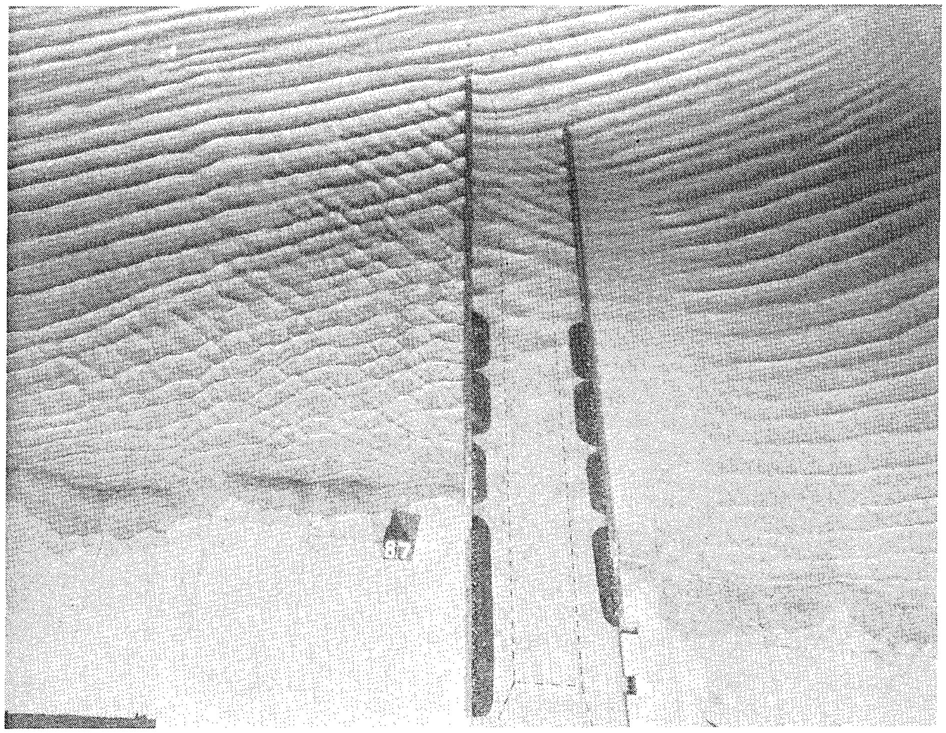
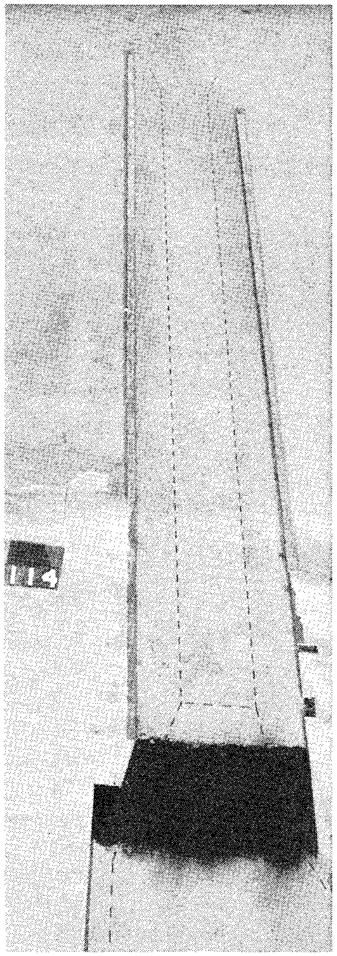
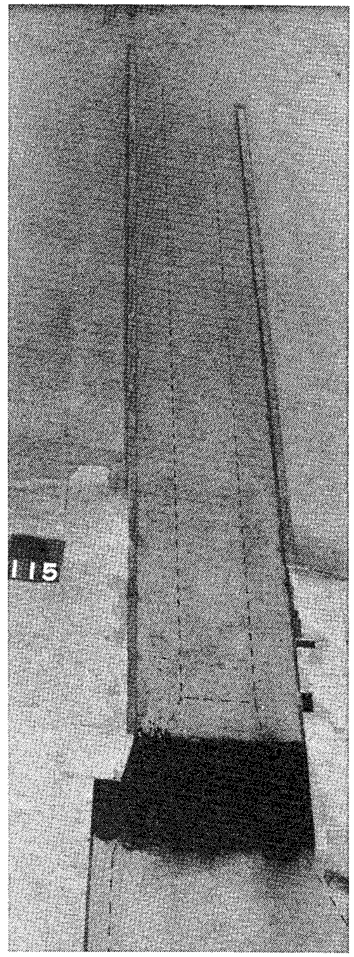


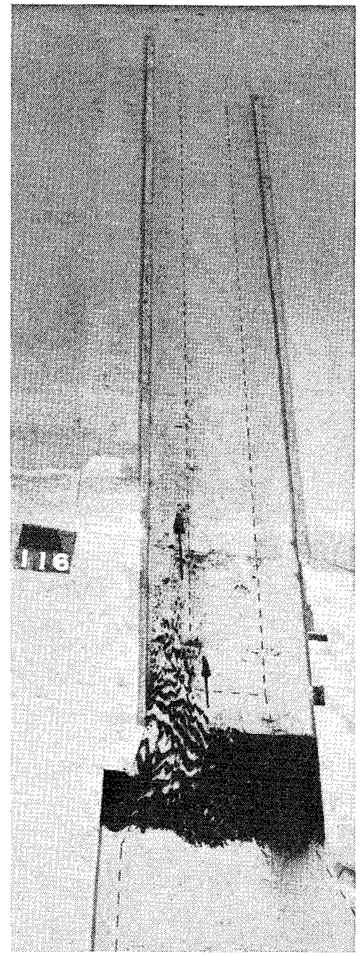
Photo 67. Typical wave patterns for Plan 3BB; 6.5-sec, 8.0-ft, 50-year all-season test waves from 354 deg; swl = +4.7 ft LWD



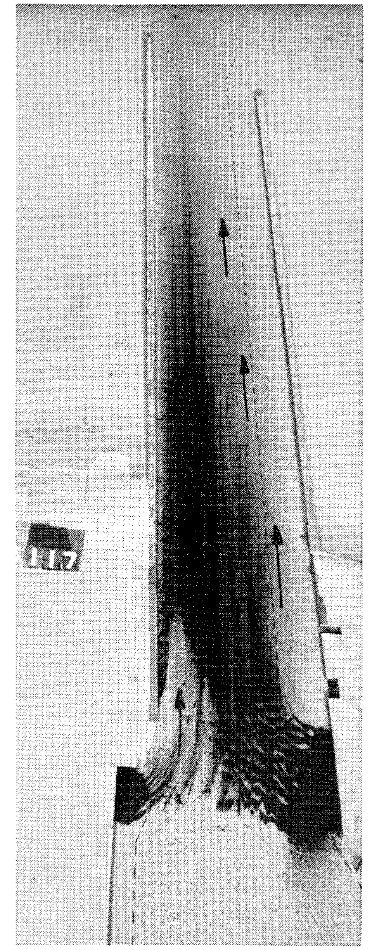
2-year discharge
(18,000 cfs)



10-year discharge
(24,200 cfs)

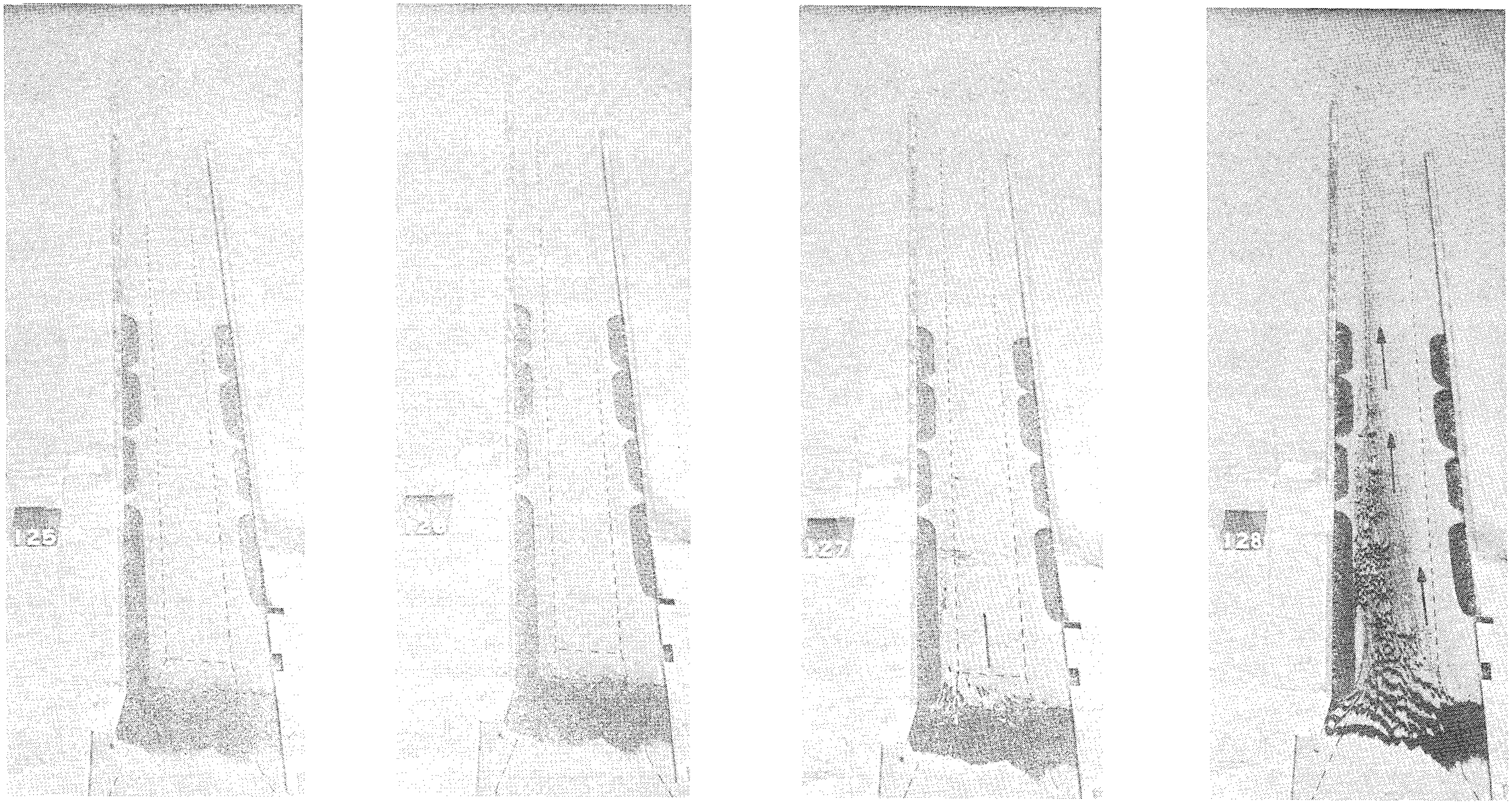


100-year discharge
(31,300 cfs)



Greater than 100-year
discharge (42,100 cfs)

Photo 68. Riverine (bed-load) sediment patterns for various river discharge for existing conditions



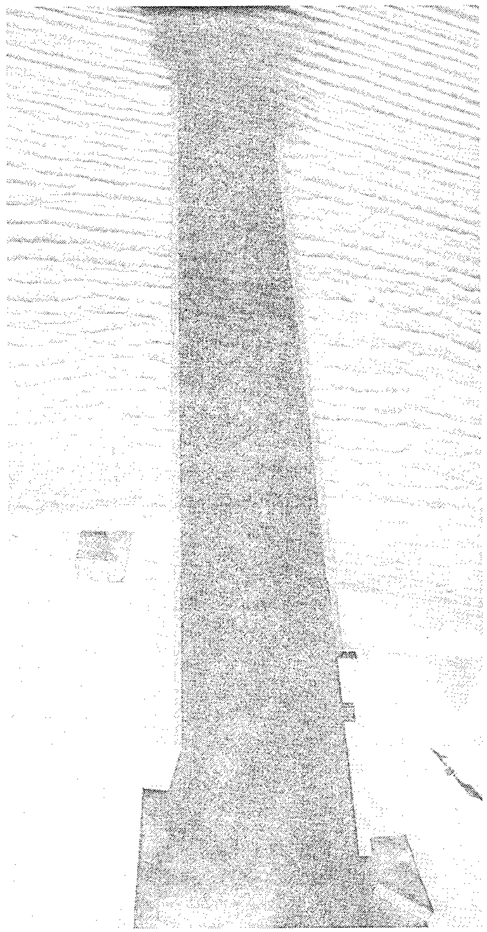
2-year discharge (18,000 cfs)

10-year discharge (24,200 cfs)

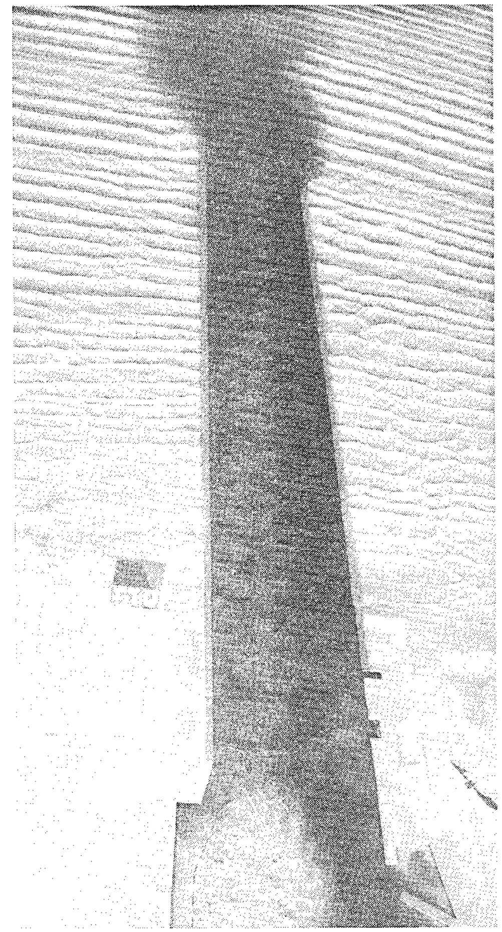
100-year discharge (31,300 cfs)

Greater than 100-year discharge (42,100 cfs)

Photo 69. Riverine (bed-load) sediment patterns for various river discharge for Plan 3BB

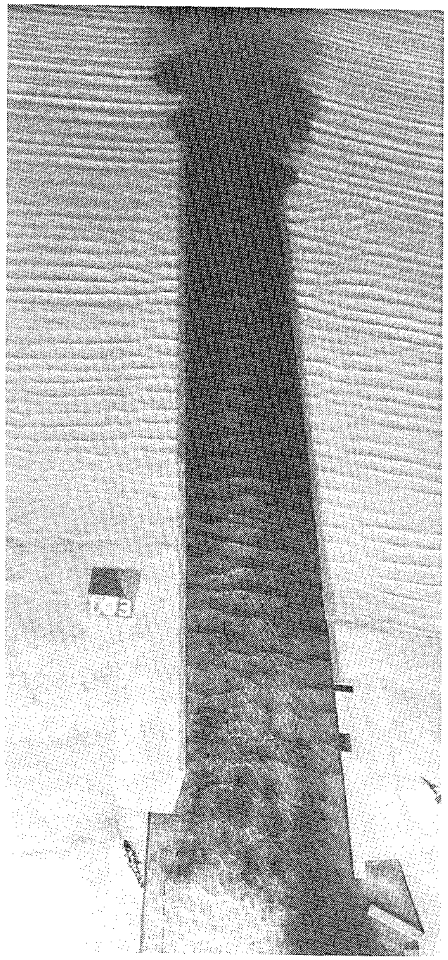


18,000-cfs discharge

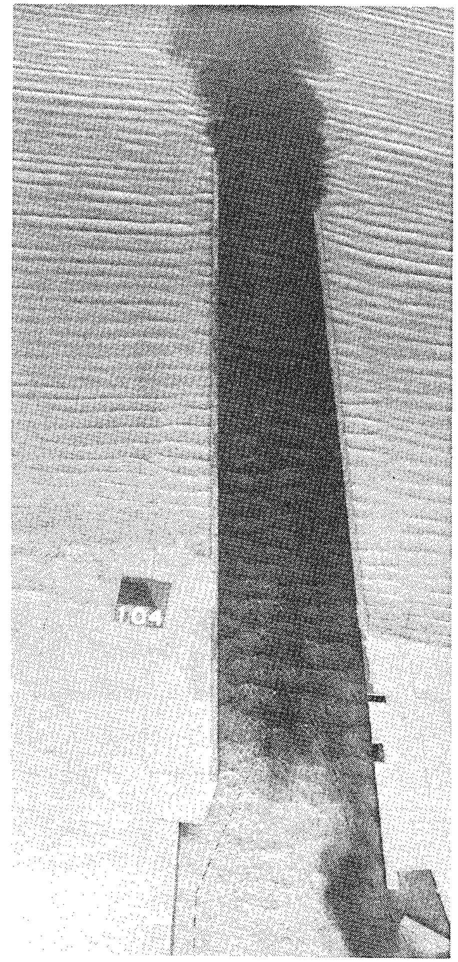


24,200-cfs discharge

Photo 70. Movement of river plume for existing conditions; 5.8-sec, 7.1-ft, 5-year navigation season test waves from 49 deg

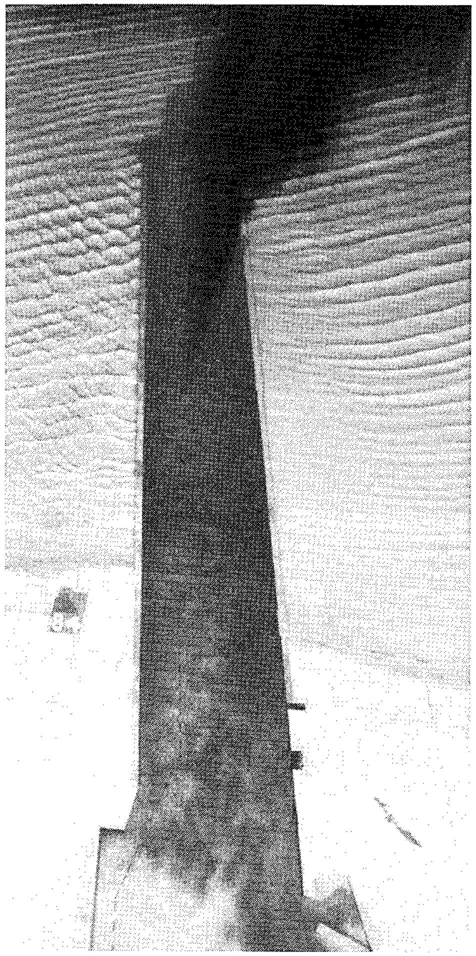


18,000-cfs discharge

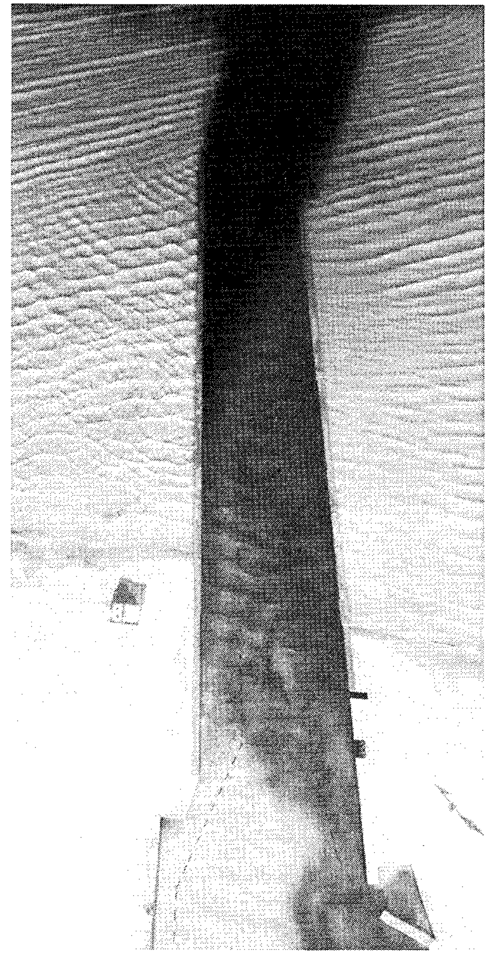


24,200-cfs discharge

Photo 71. Movement of river plume for existing conditions; 5.0-sec, 5.2-ft, 5-year navigation season test waves from 34 deg

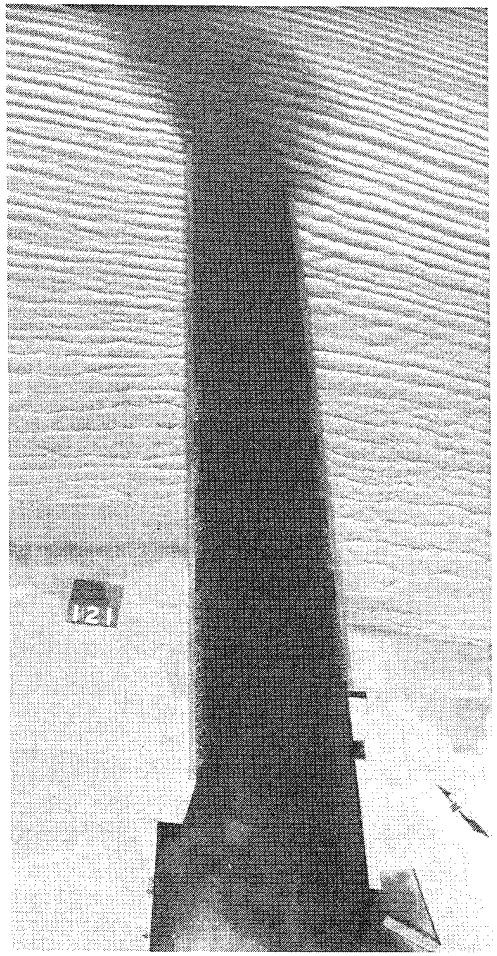


18,000-cfs discharge

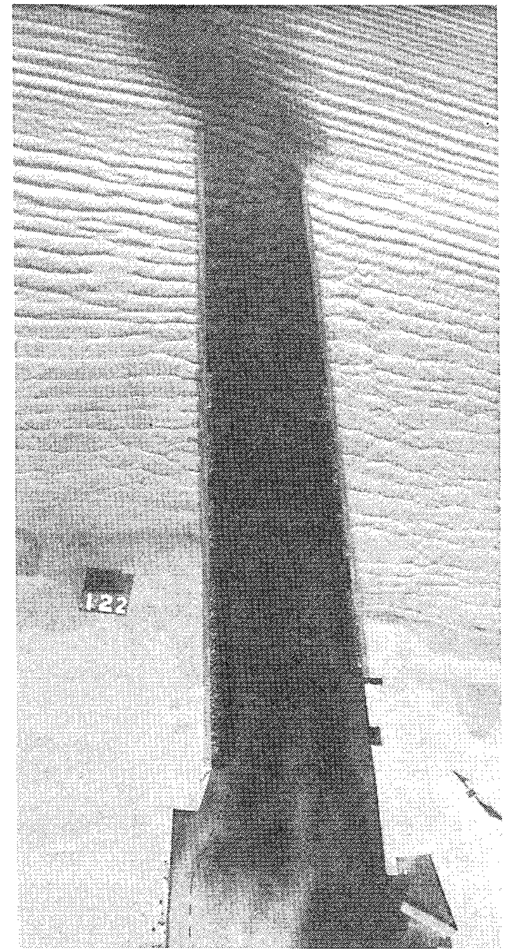


24,200-cfs discharge

Photo 72. Movement of river plume for existing conditions; 5.7-sec, 6.0-ft, 5-year navigation season test waves from 354 deg

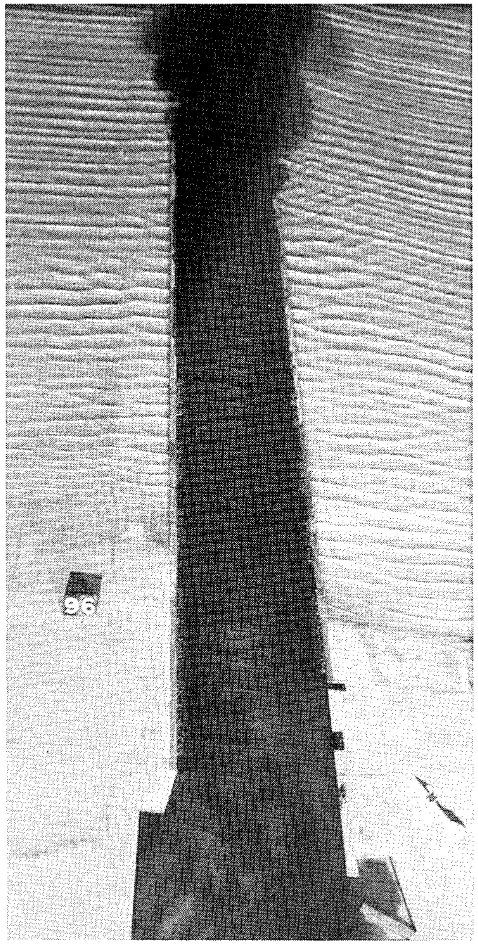


18,000-cfs discharge

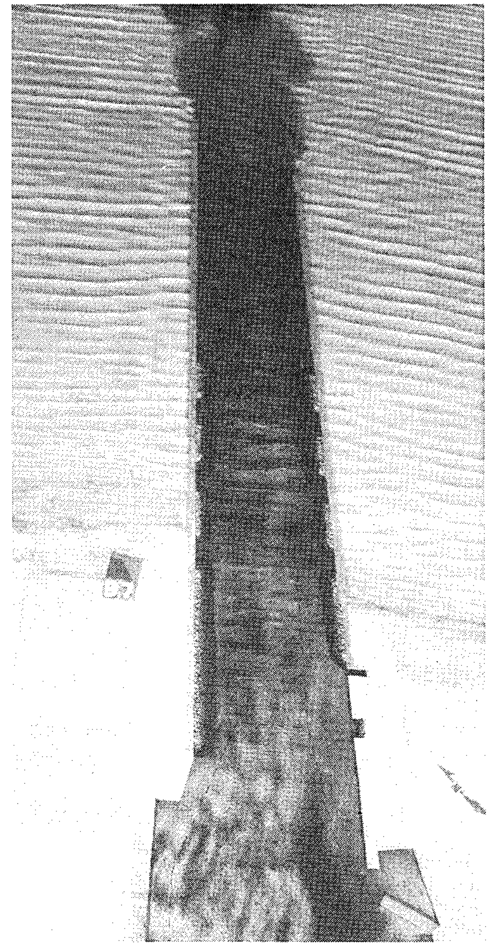


24,200-cfs discharge

Photo 73. Movement of river plume for Plan 3BB; 5.8-sec, 7.1-ft, 5-year navigation season test waves from 49 deg

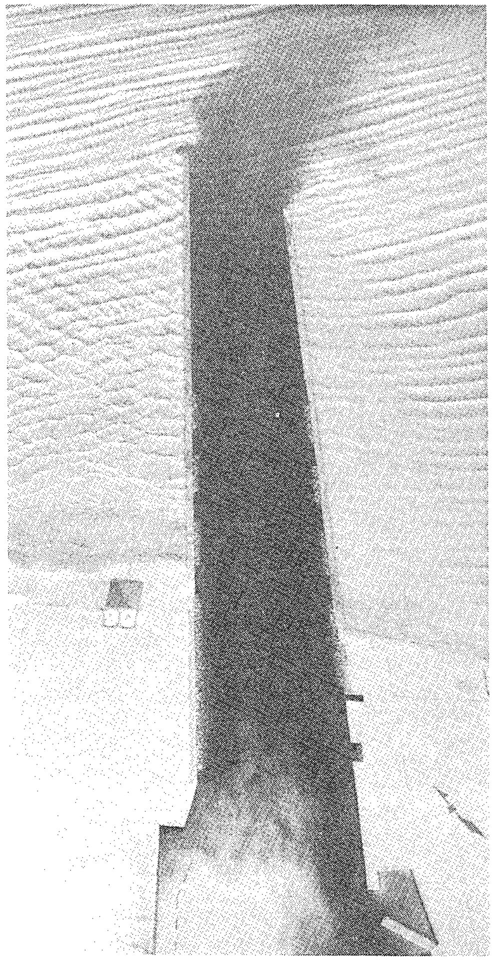


18,000-cfs discharge

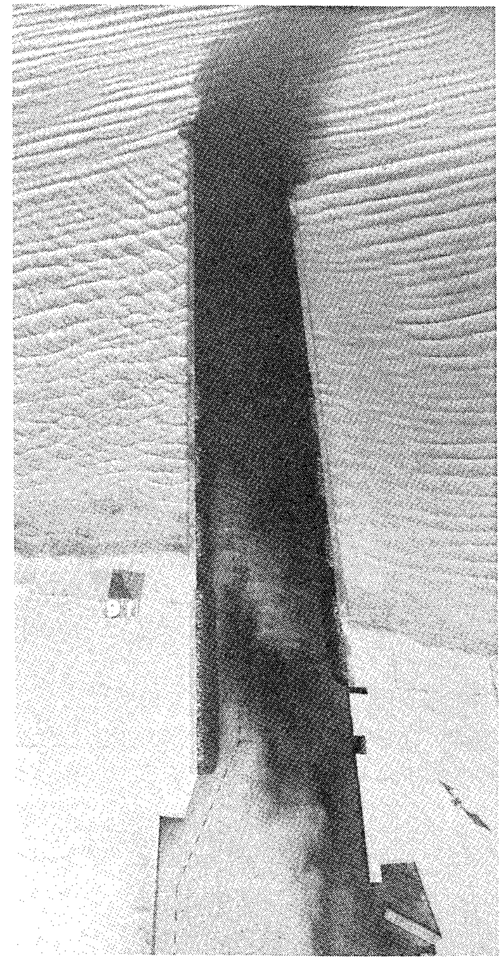


24,200-cfs discharge

Photo 74. Movement of river plume for Plan 3BB; 5.0-sec, 5.2-ft, 5-year navigation season test waves from 34 deg

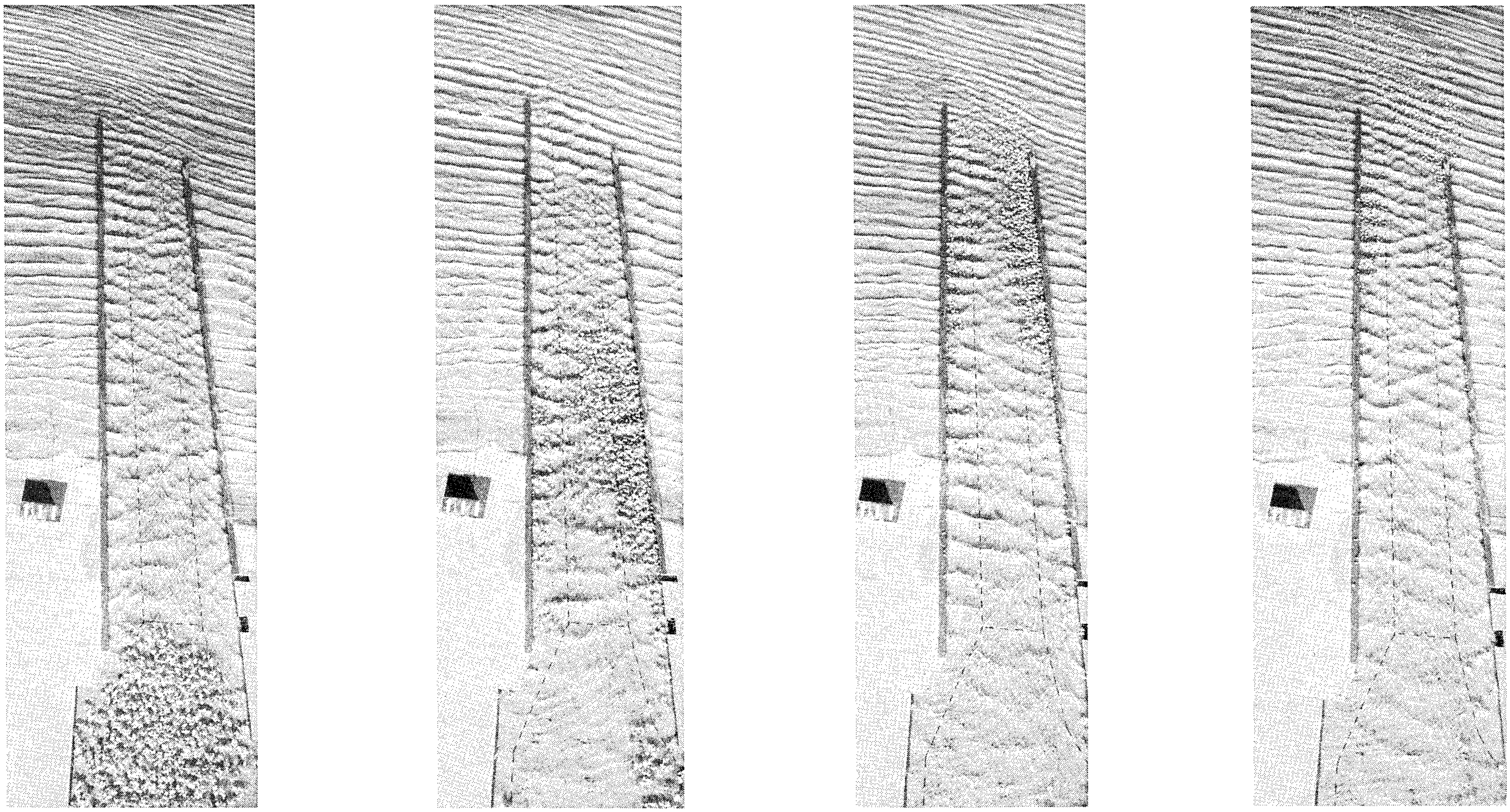


18,000-cfs discharge



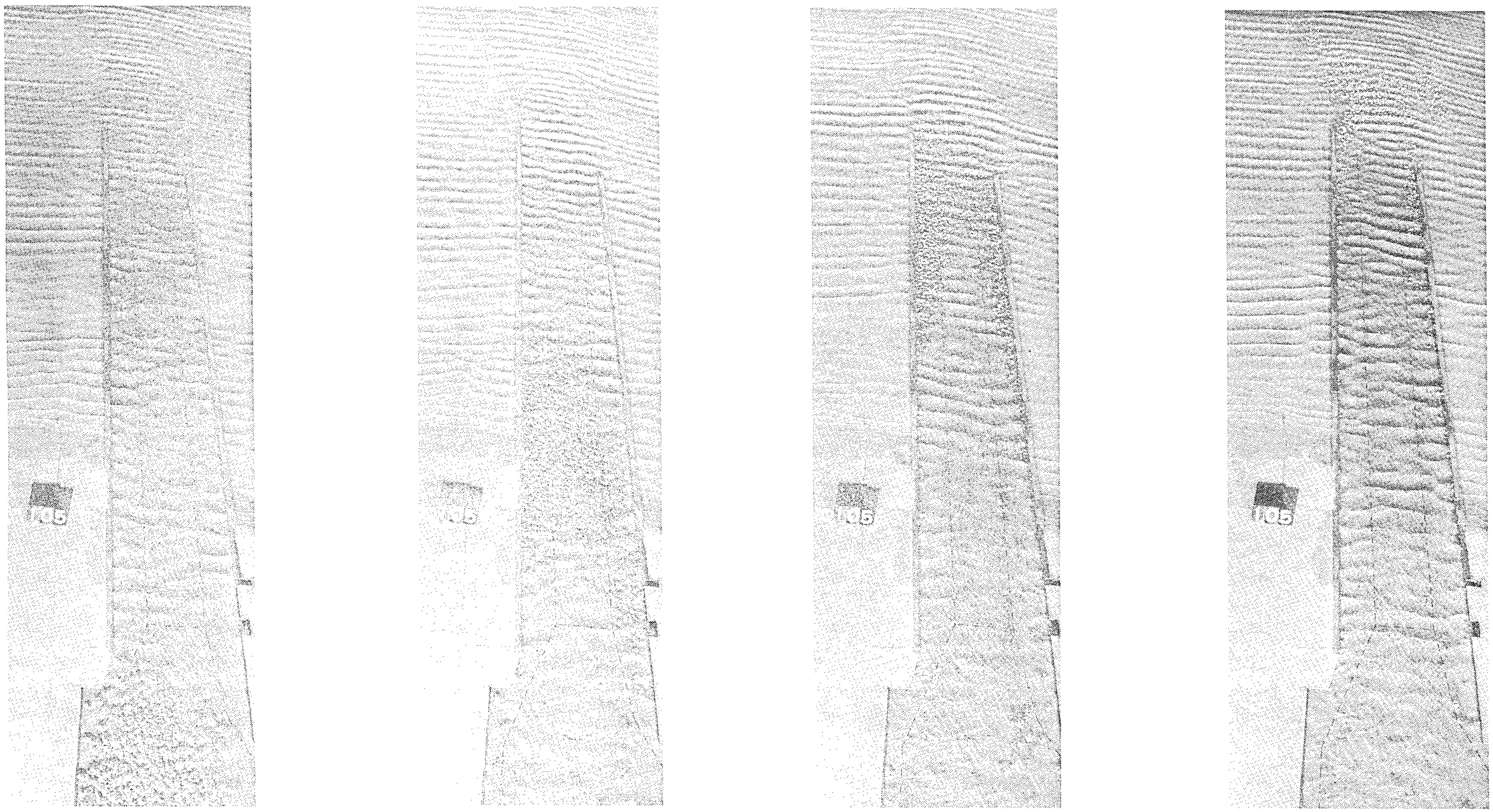
24,200-cfs discharge

Photo 75. Movement of river plume for Plan 3BB; 5.7-sec, 6.0-ft, 5-year navigation season test waves from 354 deg



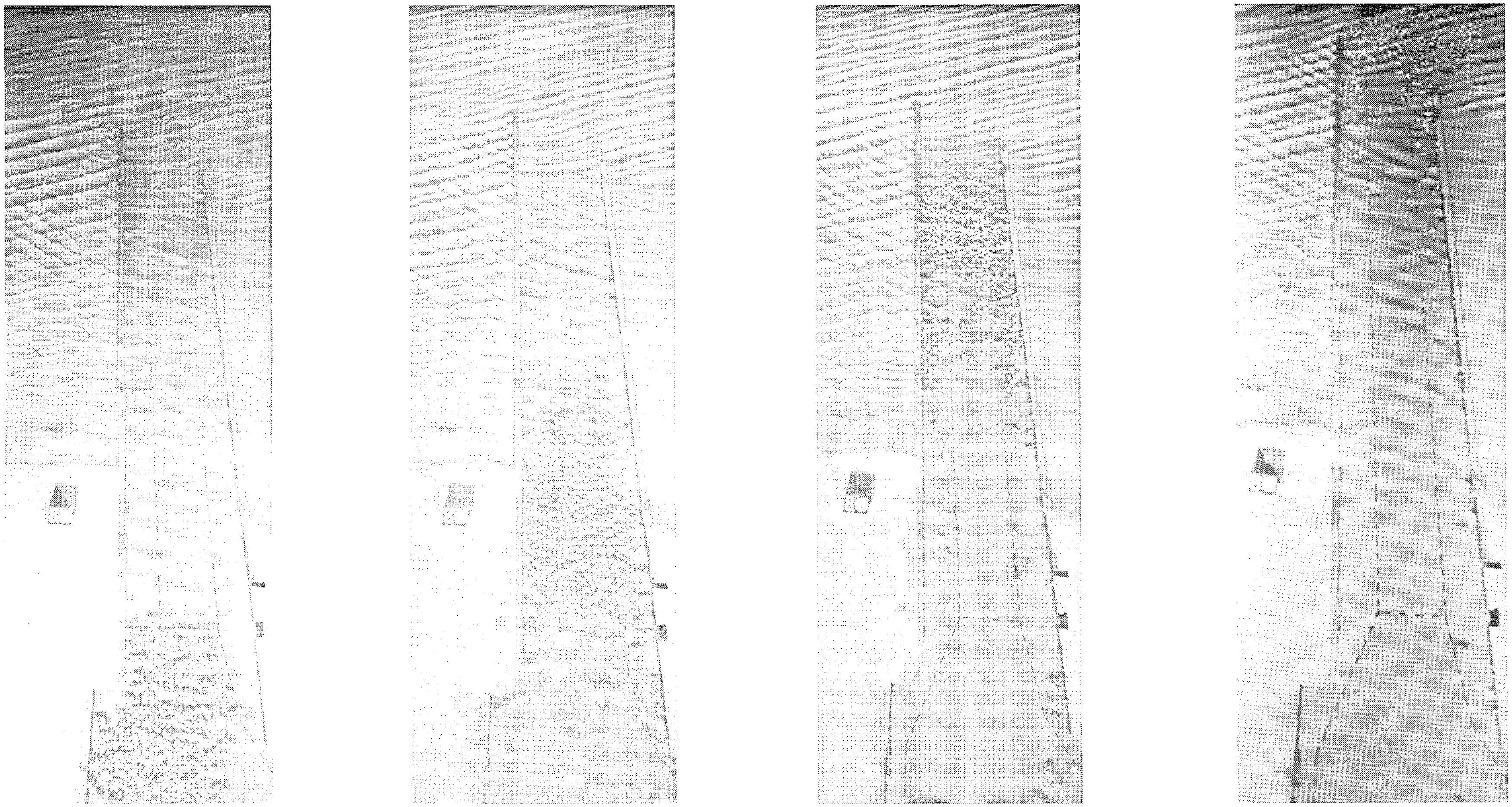
a b c d

Photo 76. Progression of confetti for river surface current tests for existing conditions; 5.8-sec, 7.1-ft, 5-year navigation season test waves from 49 deg, 18,000-cfs river discharge



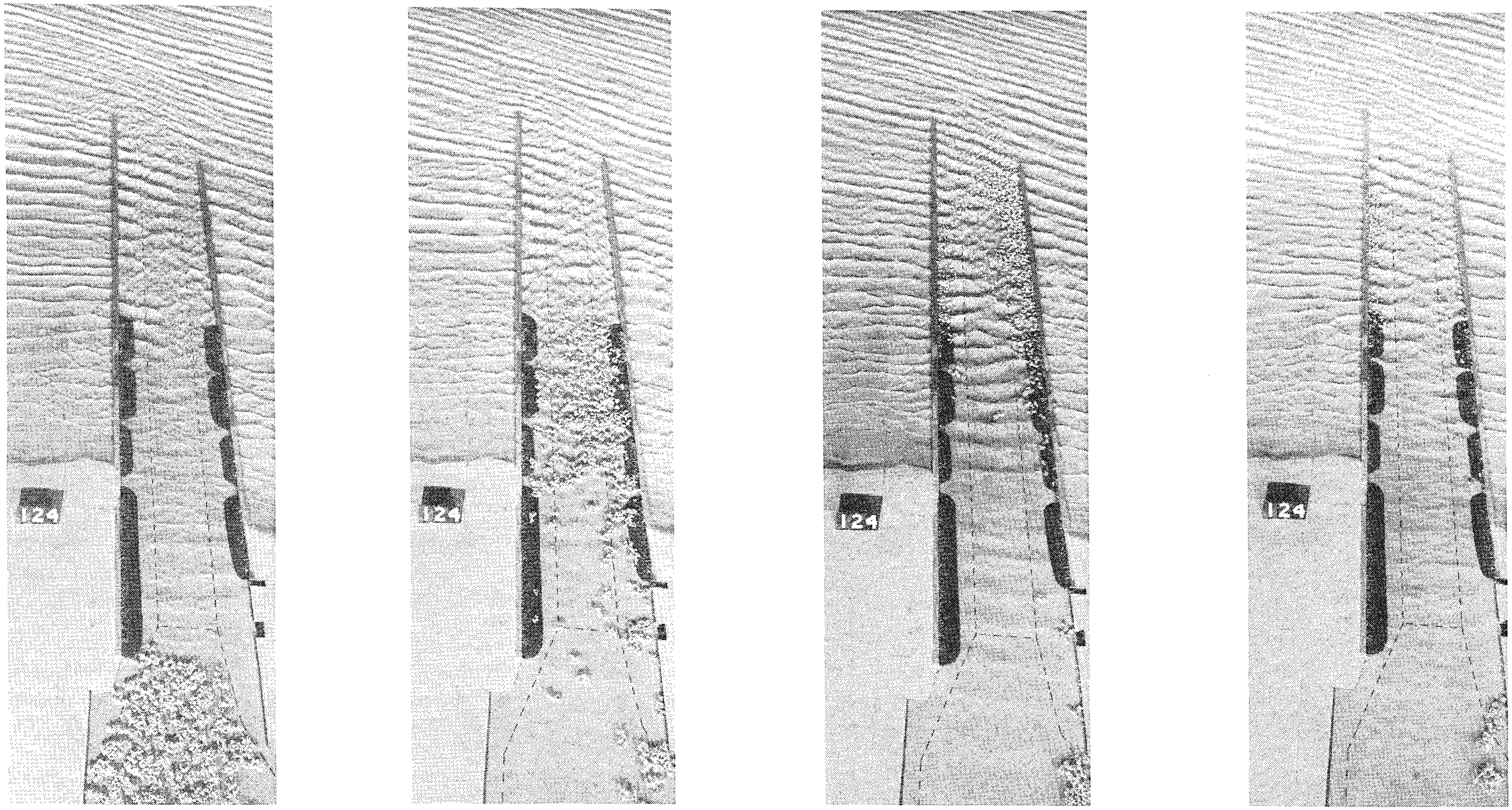
a b c d

Photo 77. Progression of confetti for river surface current tests for existing conditions; 5.0-sec, 5.2-ft, 5-year navigation season test waves from 34 deg, 18,000-cfs river discharge



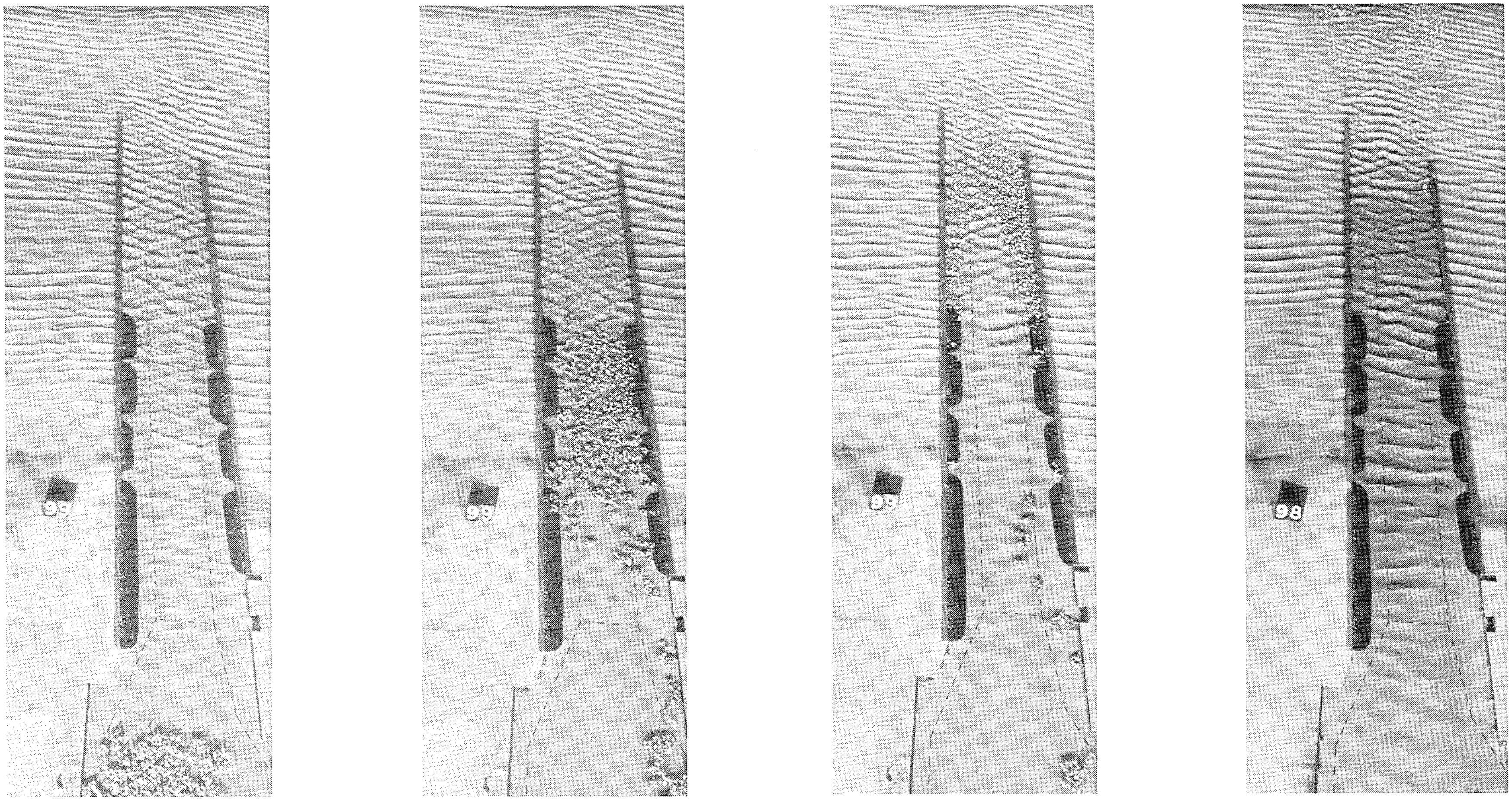
a b c d

Photo 78. Progression of confetti for river surface current tests for existing conditions; 5.7-sec, 6.0-ft, 5-year navigation season test waves from 354 deg, 18,000-cfs river discharge



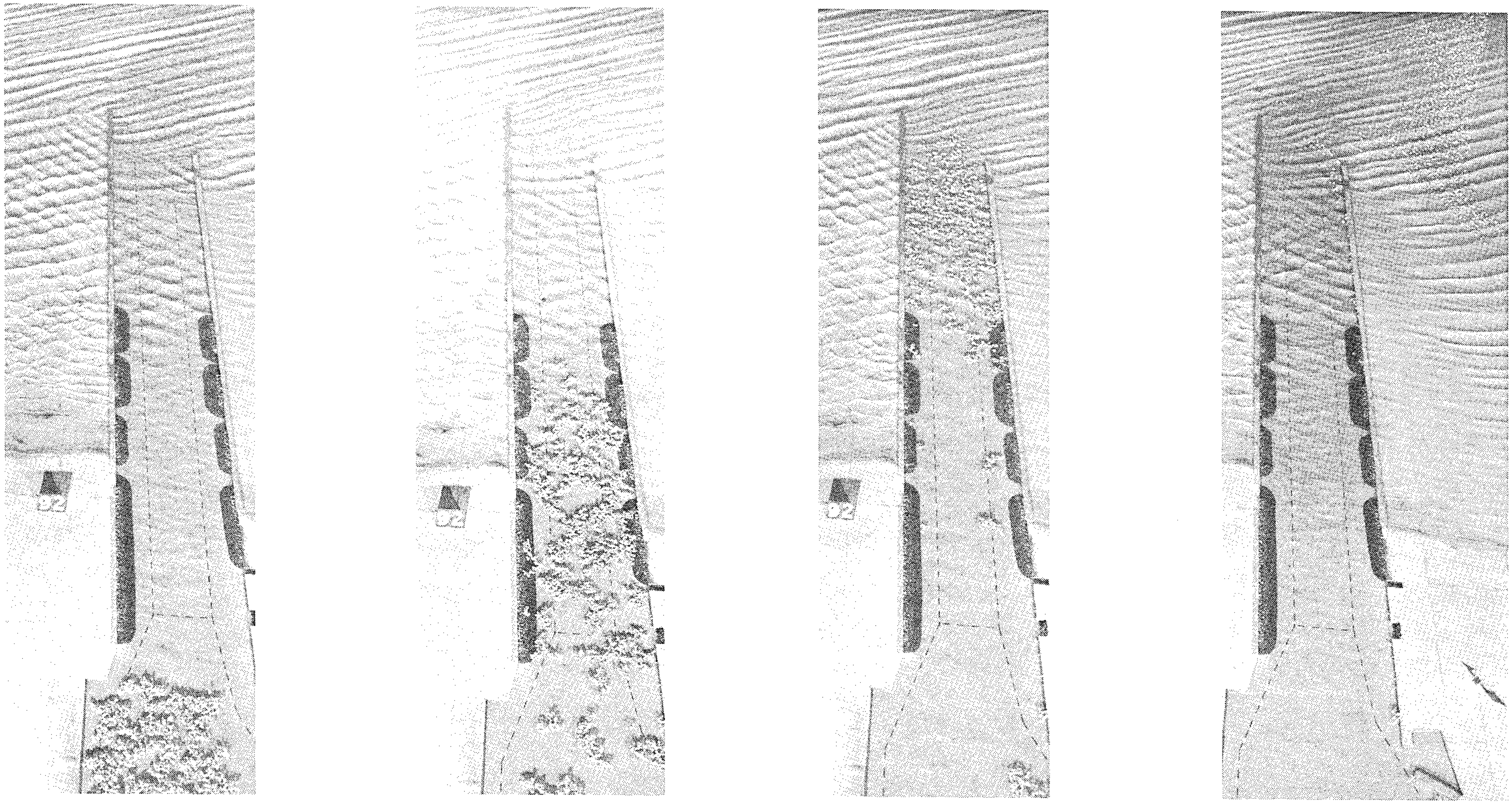
a b c d

Photo 79. Progression of confetti for river surface current tests for Plan 3BB; 5.8-sec, 7.1-ft, 5-year navigation season test waves from 49 deg, 18,000-cfs river discharge



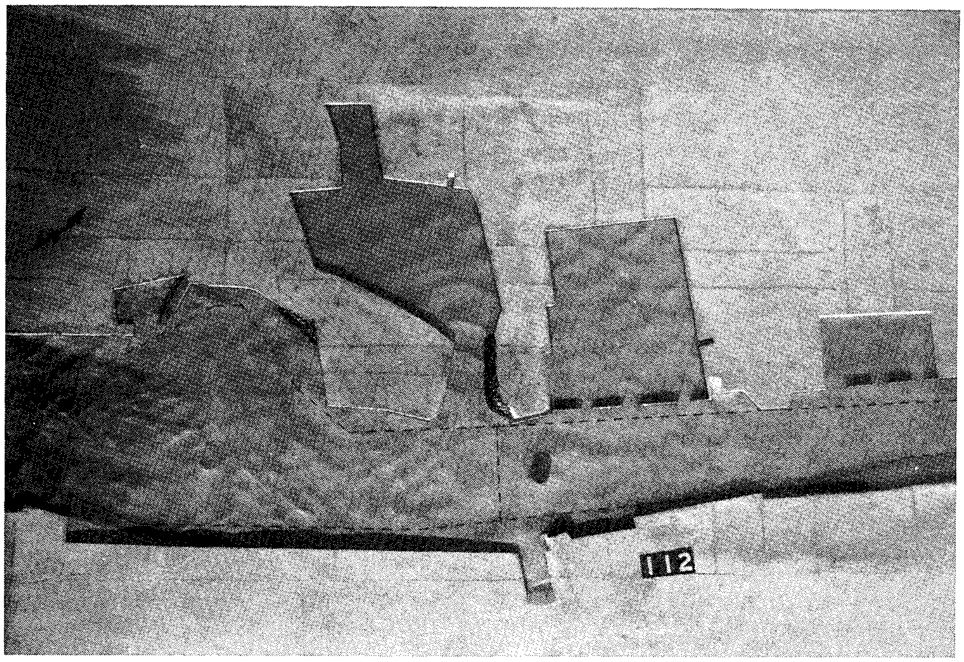
a b c d

Photo 80. Progression of confetti for river surface current tests for Plan 3BB; 5.0-sec, 5.2-ft, 5-year navigation season test waves from 34 deg, 18,000-cfs river discharge

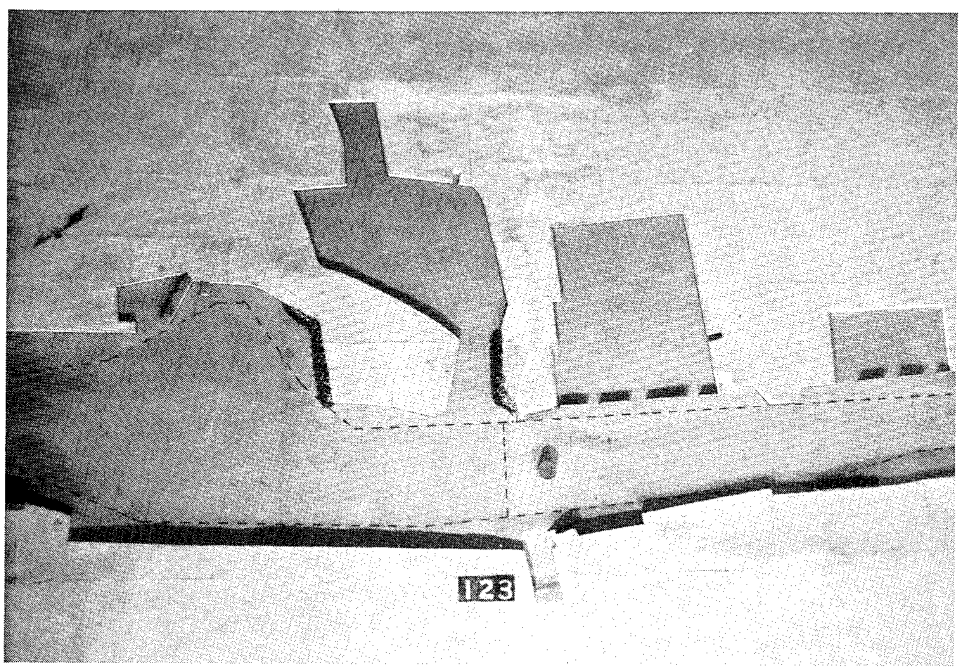


a b c d

Photo 81. Progression of confetti for river surface current tests for Plan 3BB; 5.7-sec, 6.0-ft, 5-year navigation season test waves from 354 deg, 18,000-cfs river discharge

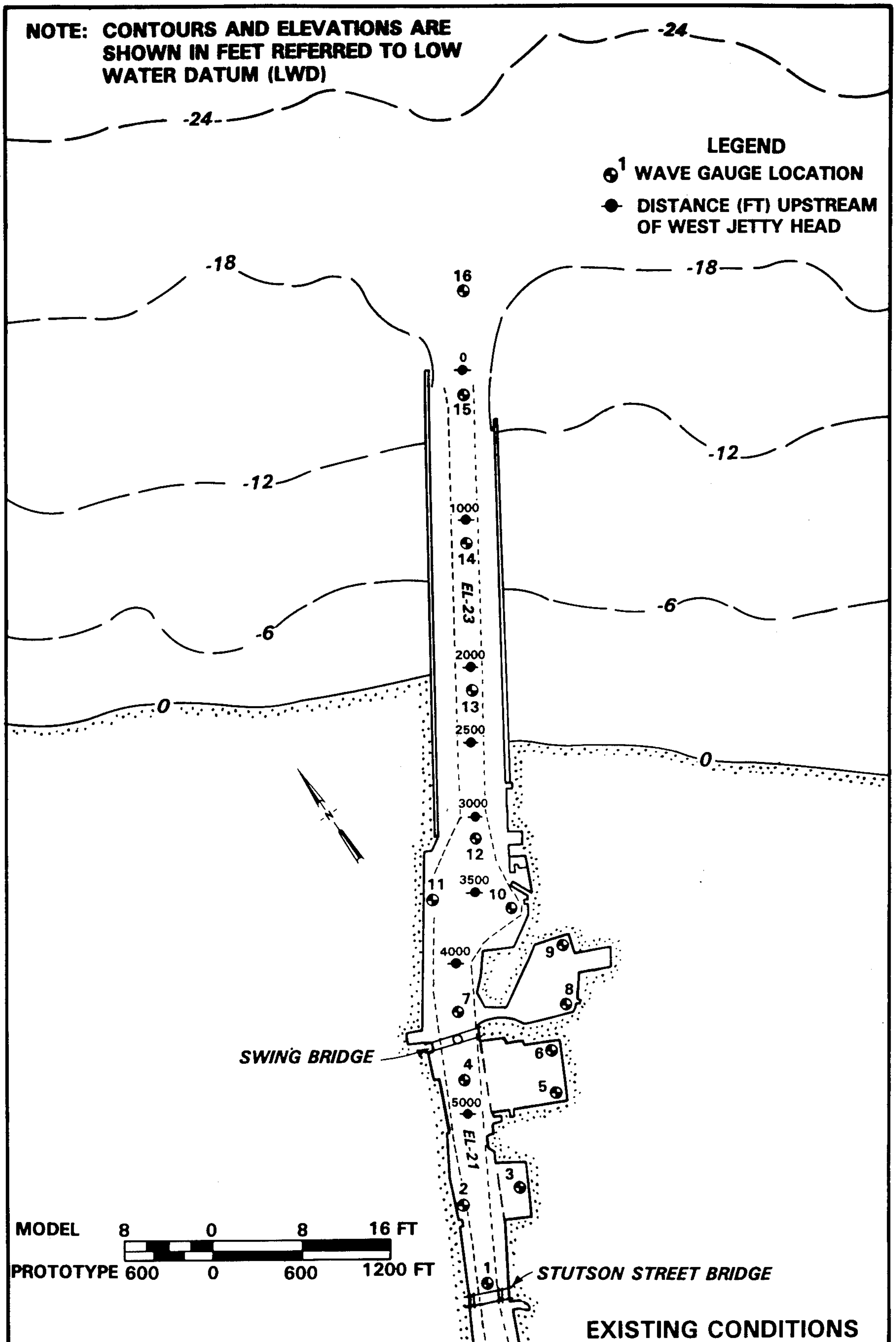


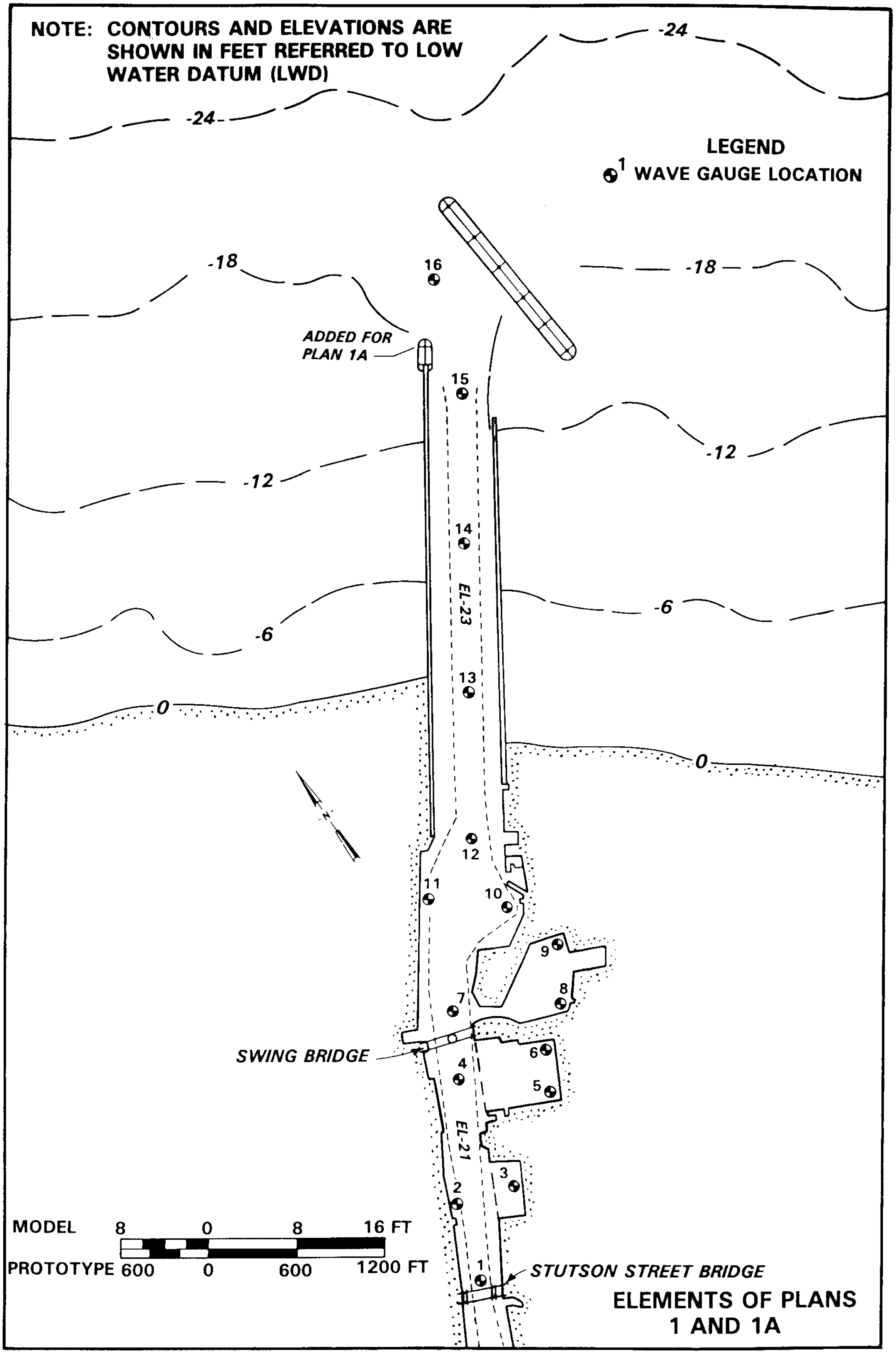
Existing conditions



Plan 3BB

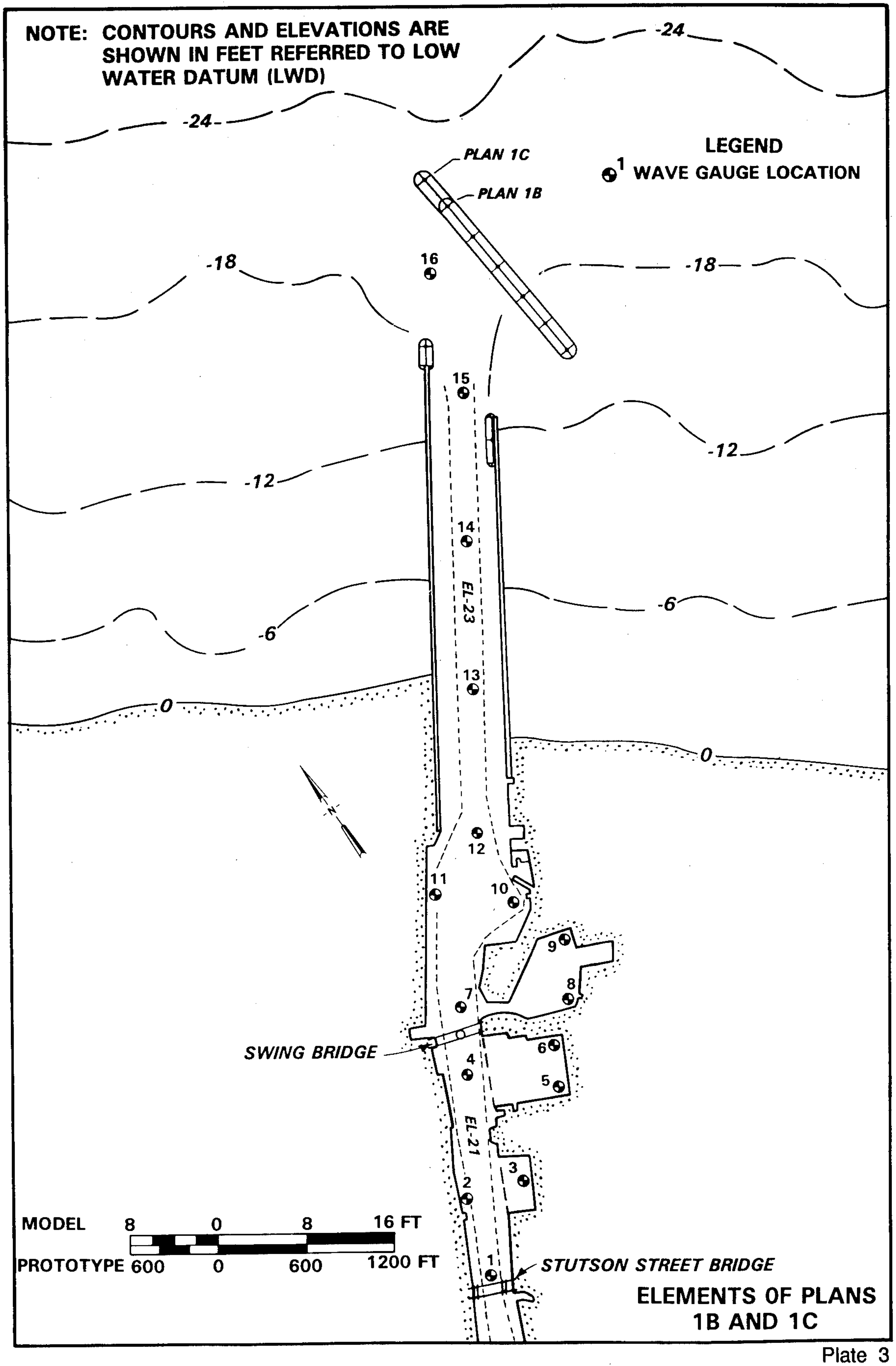
Photo 82. Comparison of wave patterns in river south of jetties for existing conditions and Plan 3BB; 6.4-sec, 9.1-ft, 20-year navigation season waves from 49 deg


NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
LEGEND
WAVE GAUGE LOCATION
DISTANCE (FT) UPSTREAM OF WEST JETTY HEAD
-24
-24
-18
-18
-12
-12
-6
-6
0
0
16
0
15
1000
14
EL-23
2000
13
2500
3000
12
11
3500
10
9
4000
8
7
SWING BRIDGE
6
4
5
5000
EL-21
3
2
1
STUTSON STREET BRIDGE
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
EXISTING CONDITIONS



NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
LEGEND
1 WAVE GAUGE LOCATION
-24
-18
-12
-6
0
ADDED FOR PLAN 1A
EL-23
EL-21
SWING BRIDGE
STUTSON STREET BRIDGE
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
ELEMENTS OF PLANS 1 AND 1A

Plate 2



ELEMENTS OF PLANS 1B AND 1C

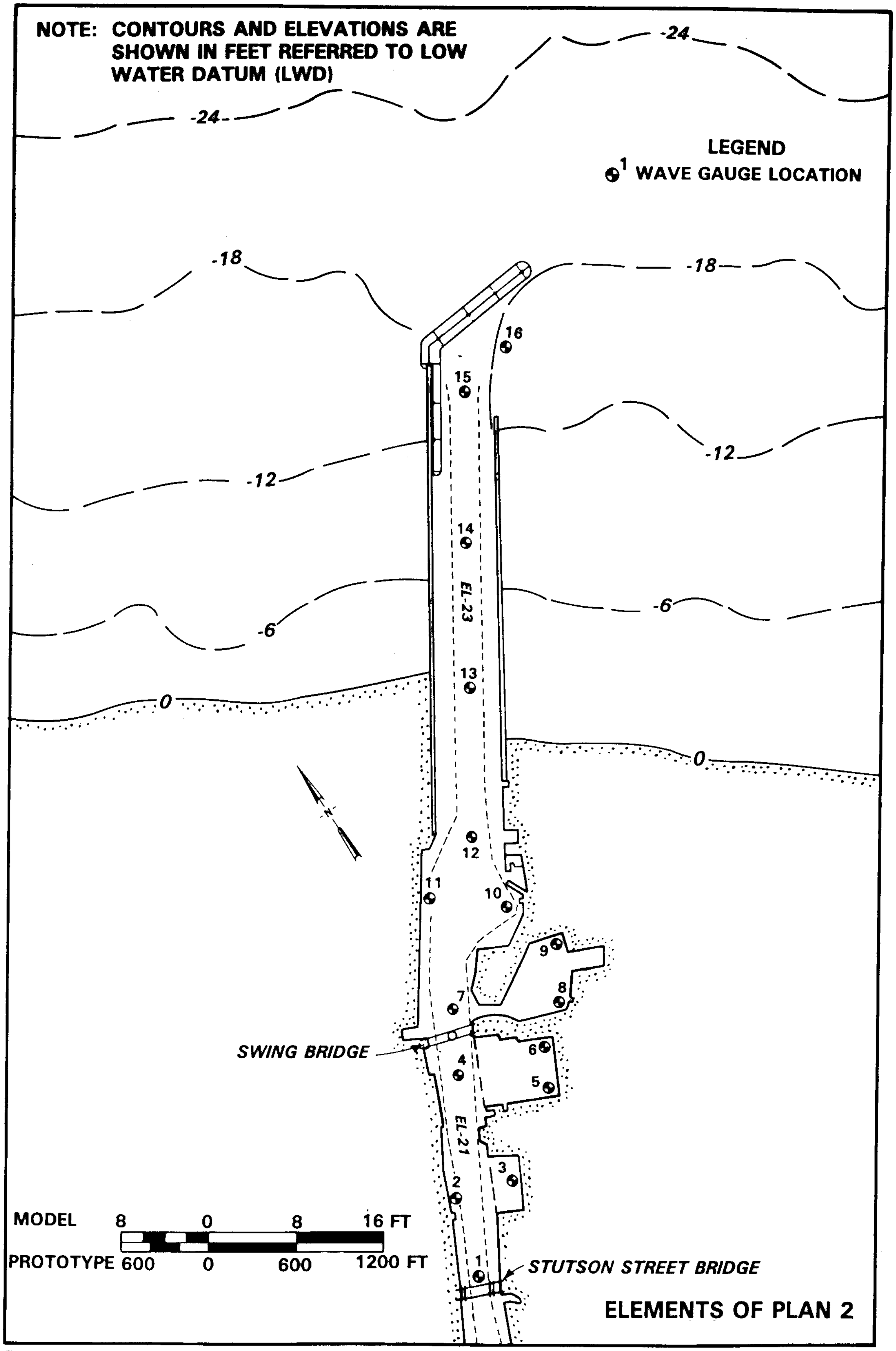
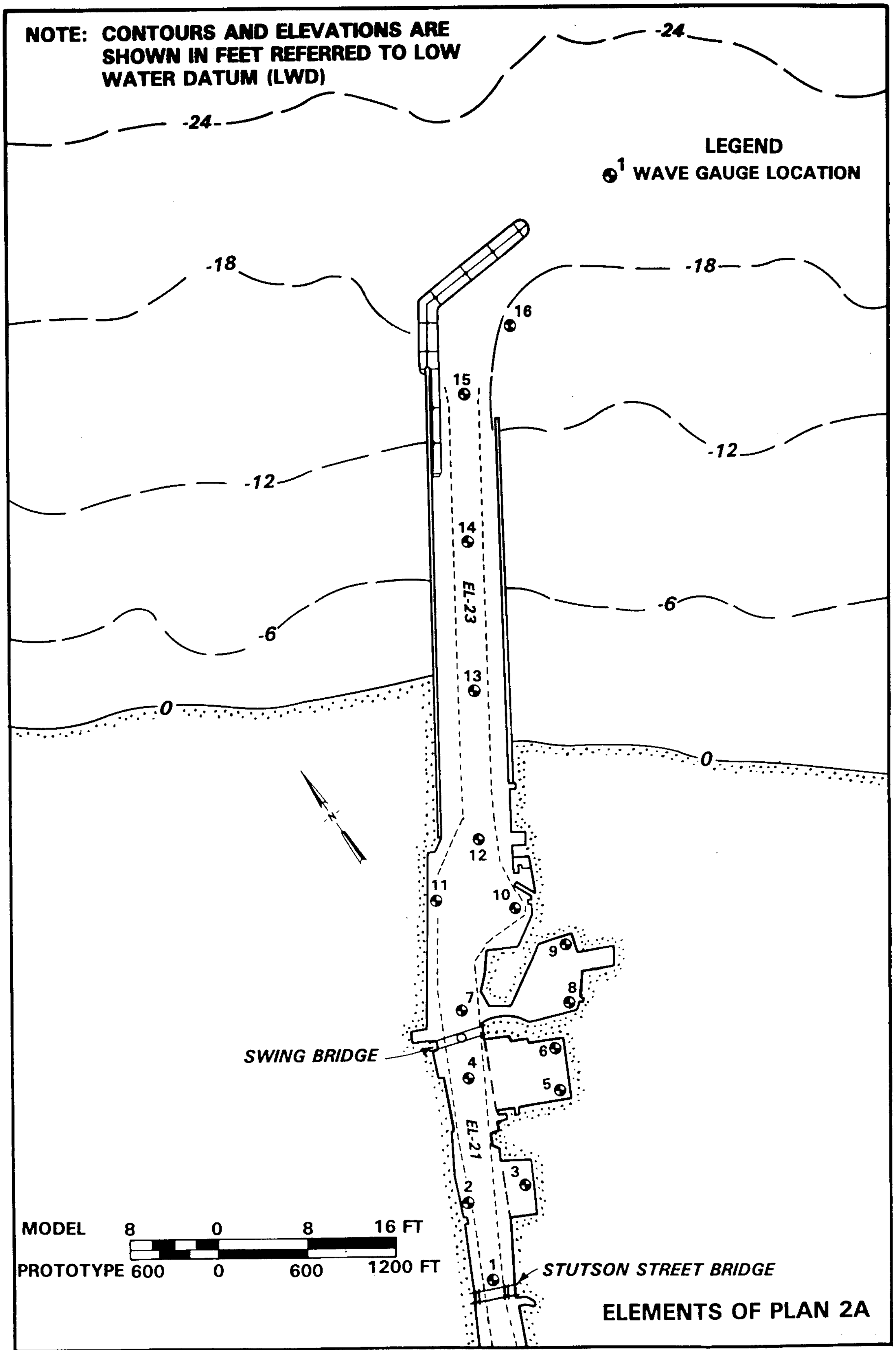

NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
LEGEND
1 WAVE GAUGE LOCATION
-24
-18
-12
-6
0
EL-23
EL-21
SWING BRIDGE
STUTSON STREET BRIDGE
N
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
ELEMENTS OF PLAN 2

Plate 4



ELEMENTS OF PLAN 2A

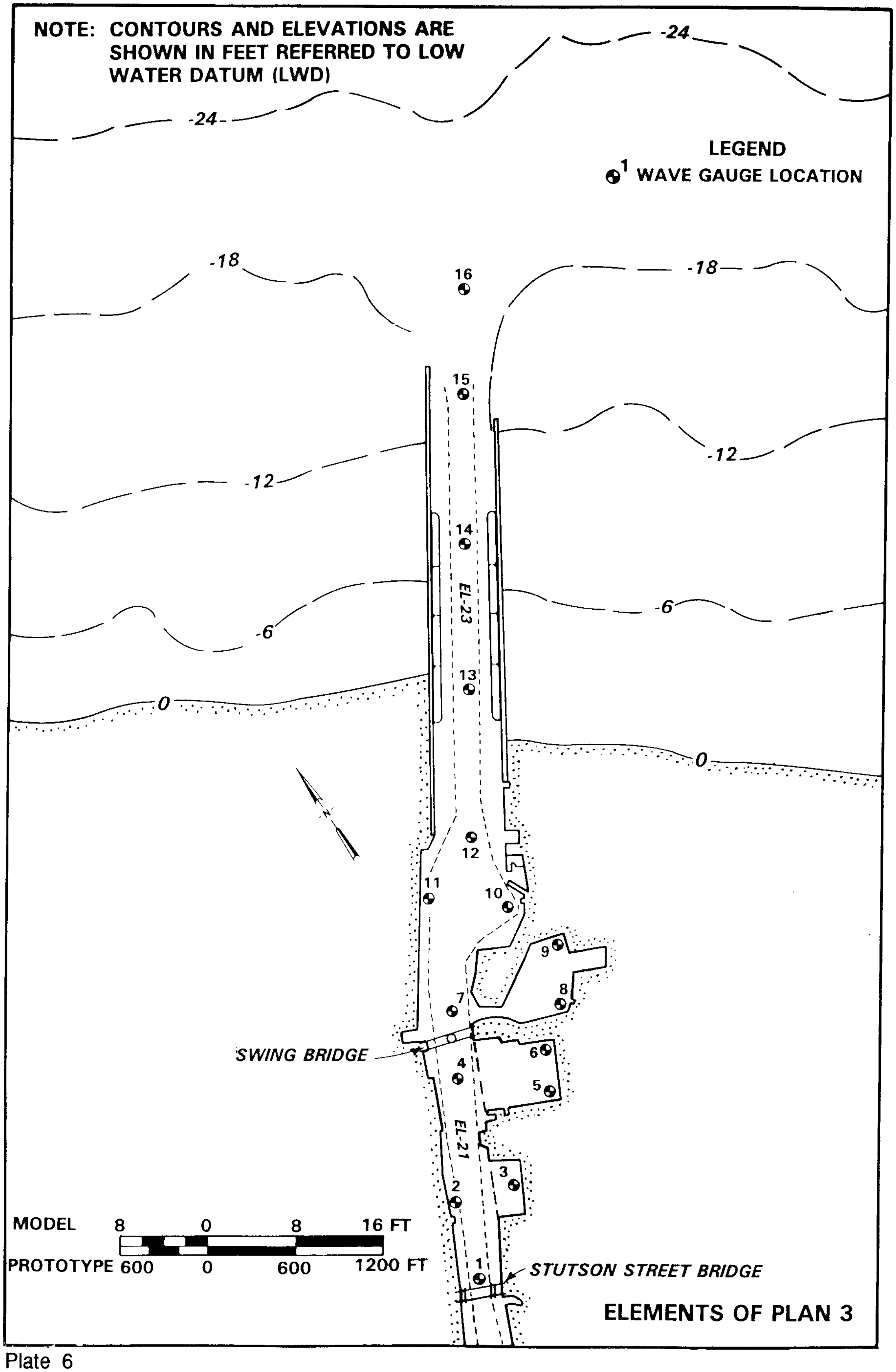
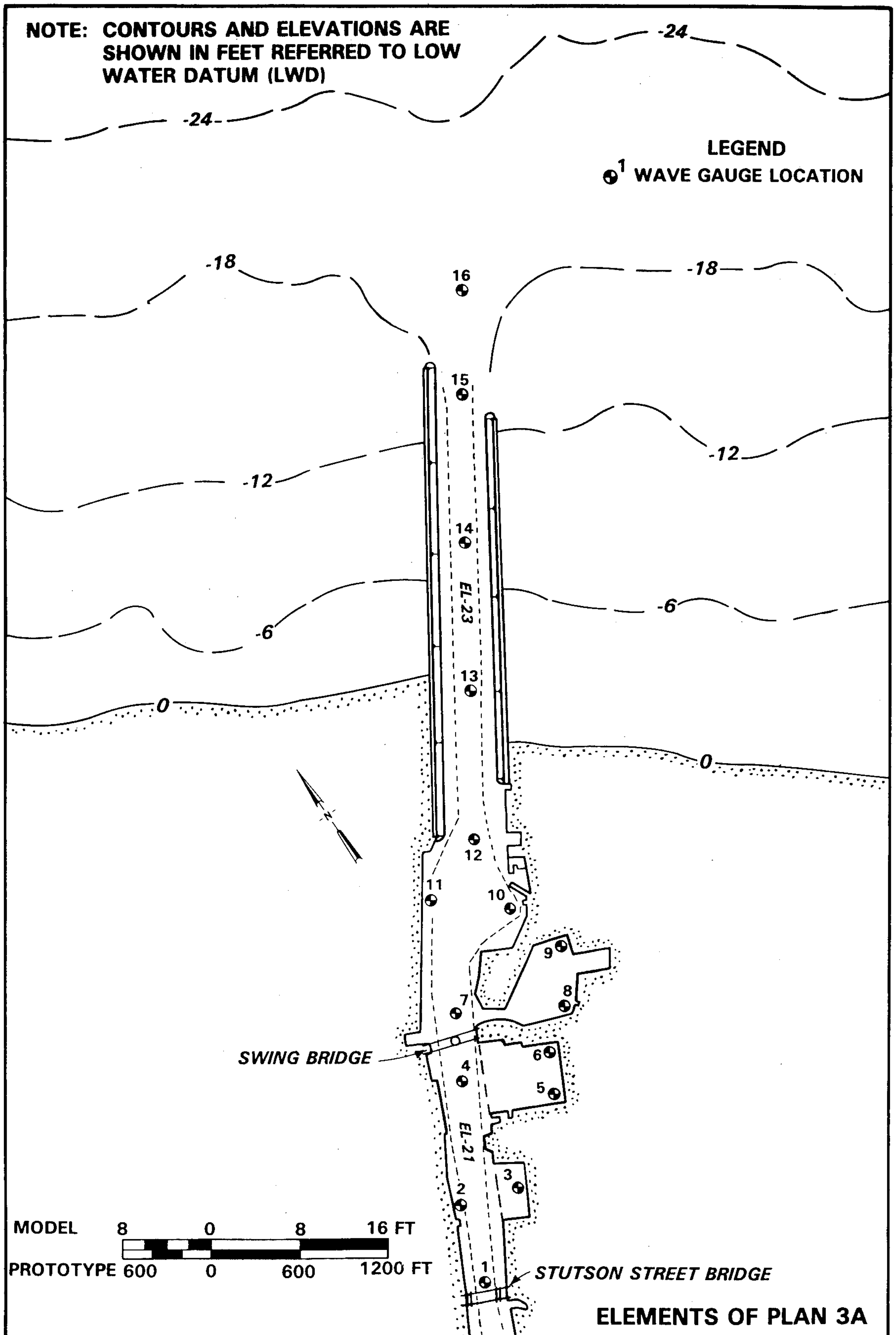
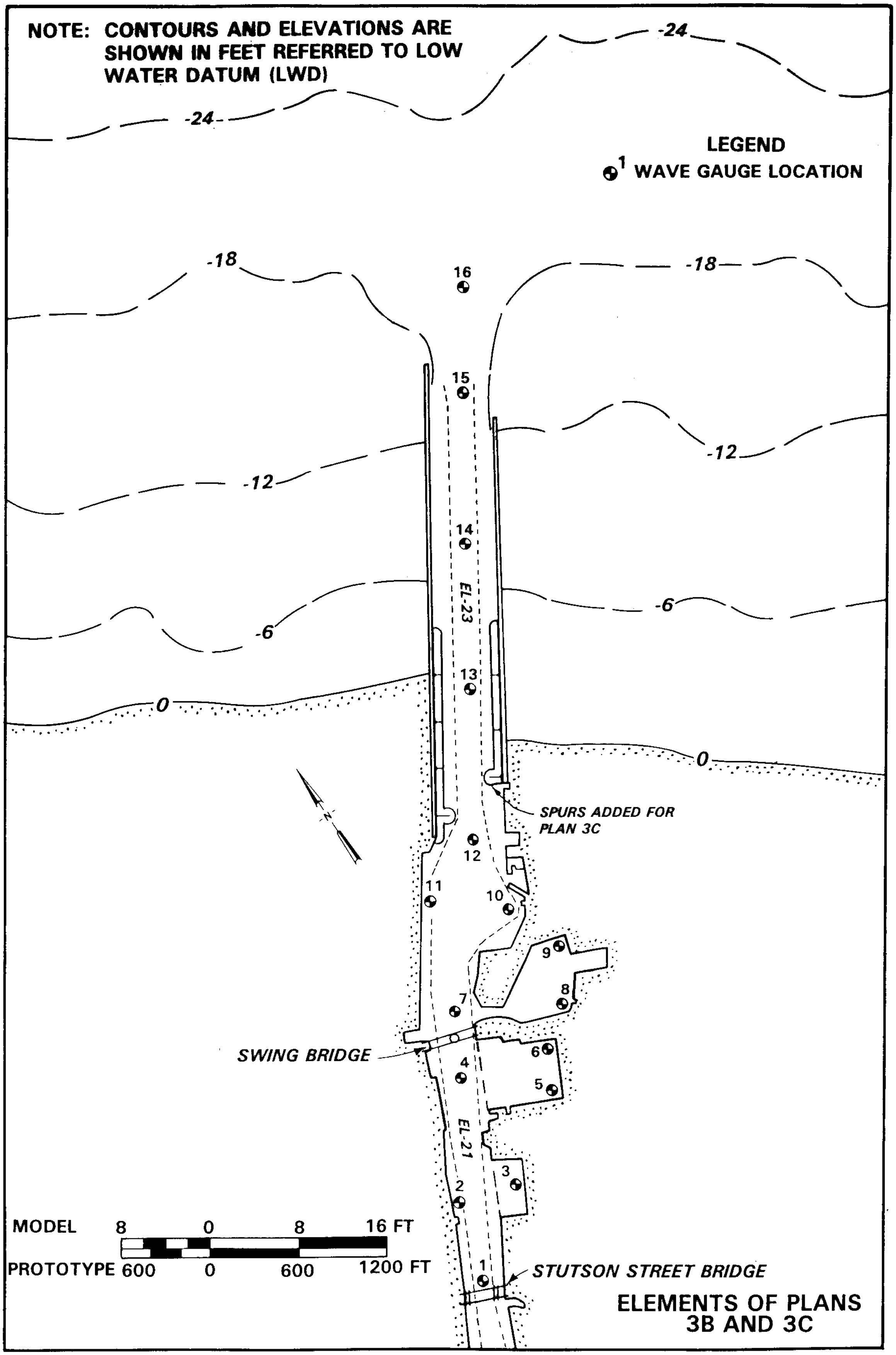

NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
LEGEND
1 WAVE GAUGE LOCATION
-24
-24
-18
-18
-12
-12
-6
-6
0
0
EL-23
EL-21
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
SWING BRIDGE
STUTSON STREET BRIDGE
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
ELEMENTS OF PLAN 3

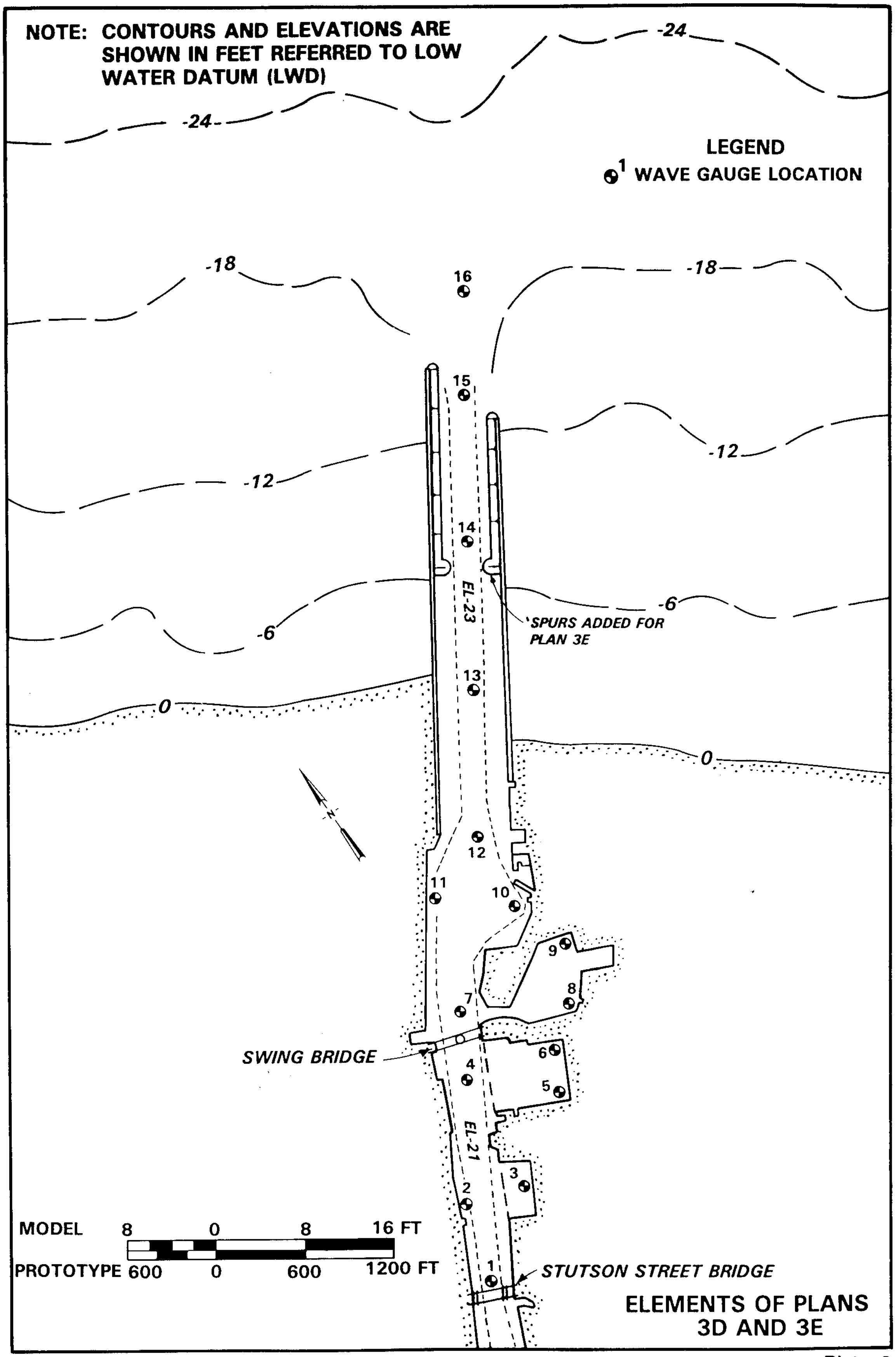
Plate 6



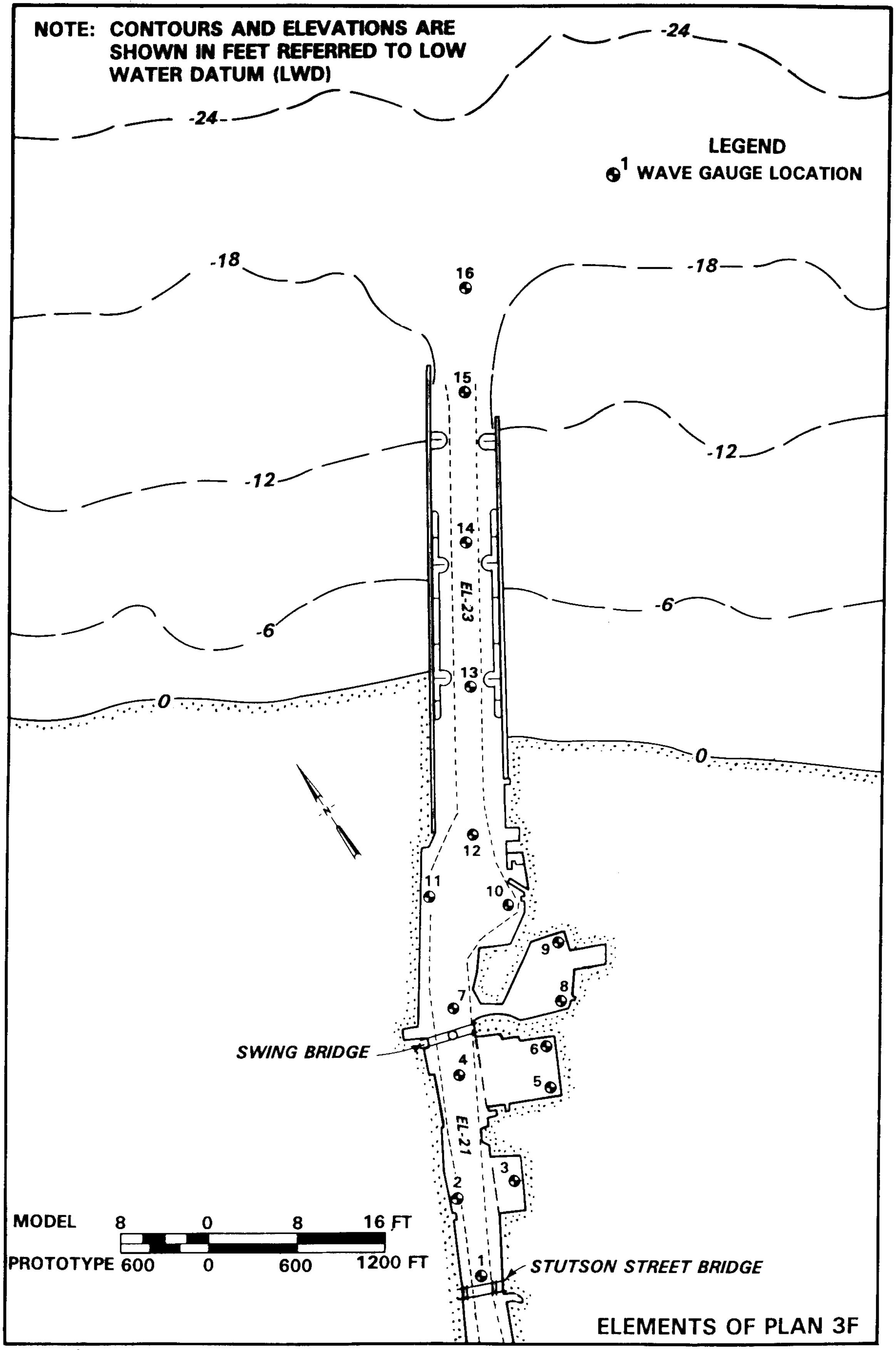
ELEMENTS OF PLAN 3A



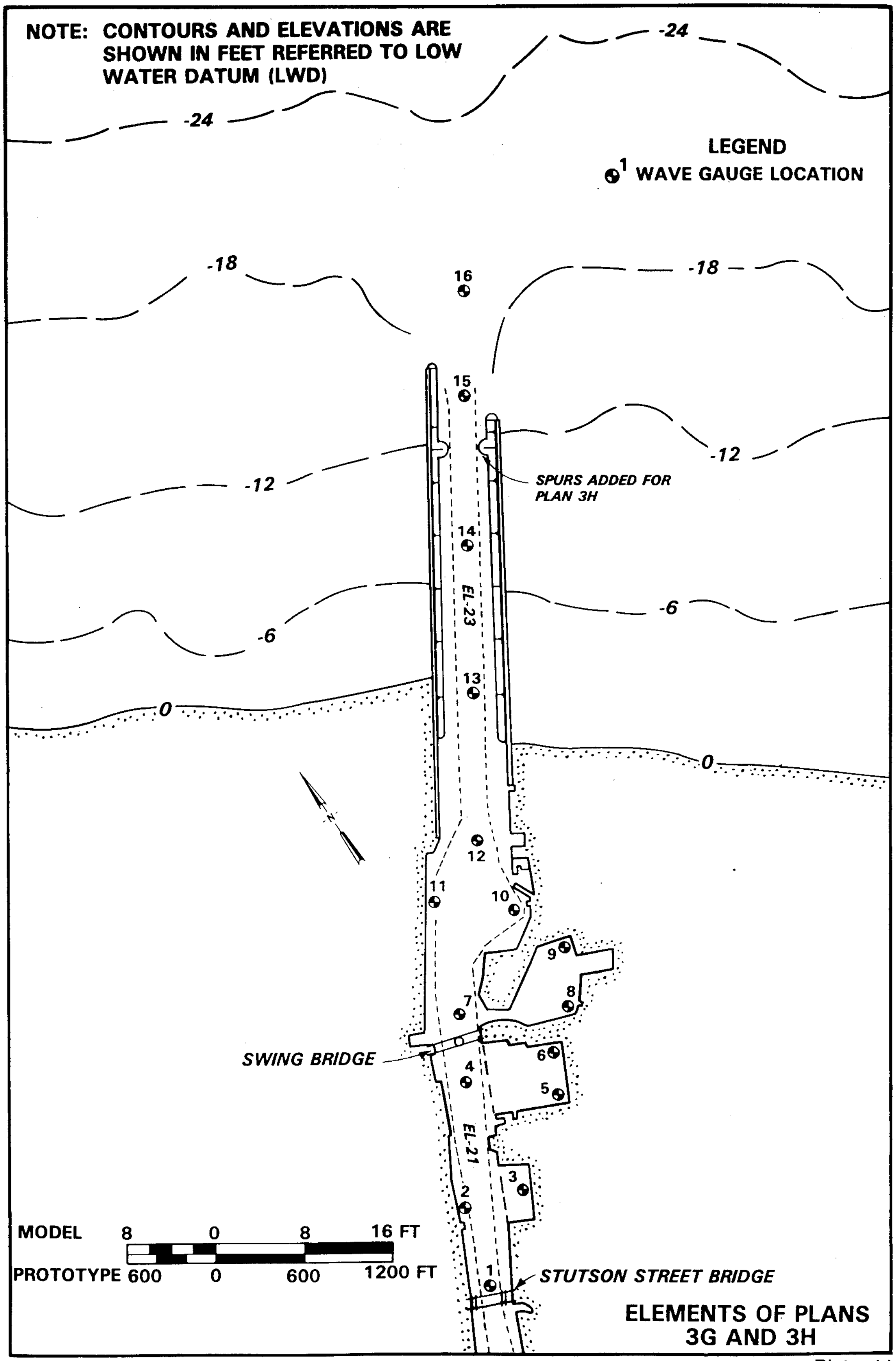
NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
-24
-24
LEGEND
1 WAVE GAUGE LOCATION
-18
-18
16
15
-12
-12
14
EL-23
-6
-6
13
0
0
N
SPURS ADDED FOR PLAN 3C
12
11
10
9
8
7
SWING BRIDGE
6
4
5
EL-21
3
2
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
1
STUTSON STREET BRIDGE
ELEMENTS OF PLANS 3B AND 3C



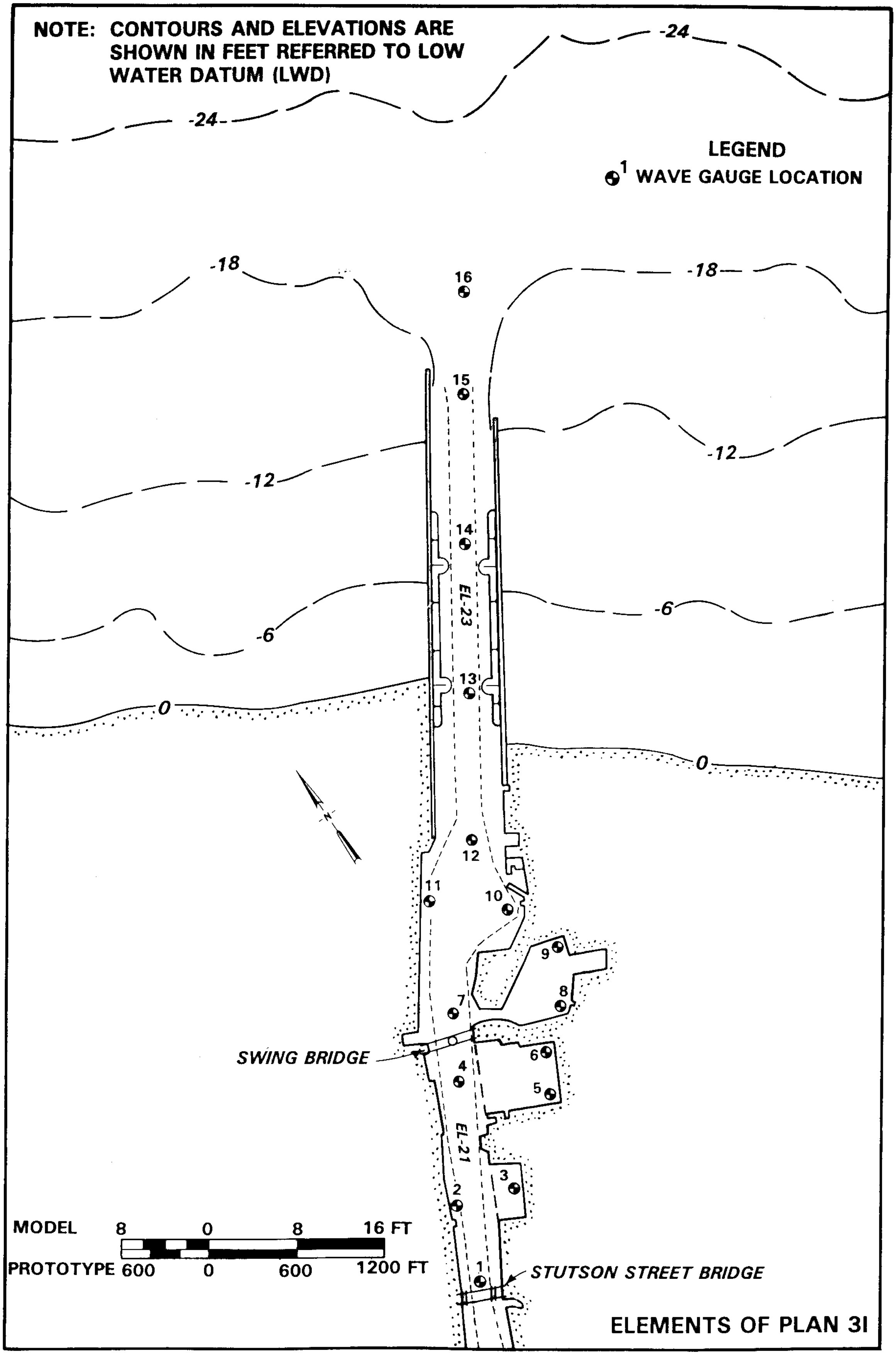
ELEMENTS OF PLANS 3D AND 3E



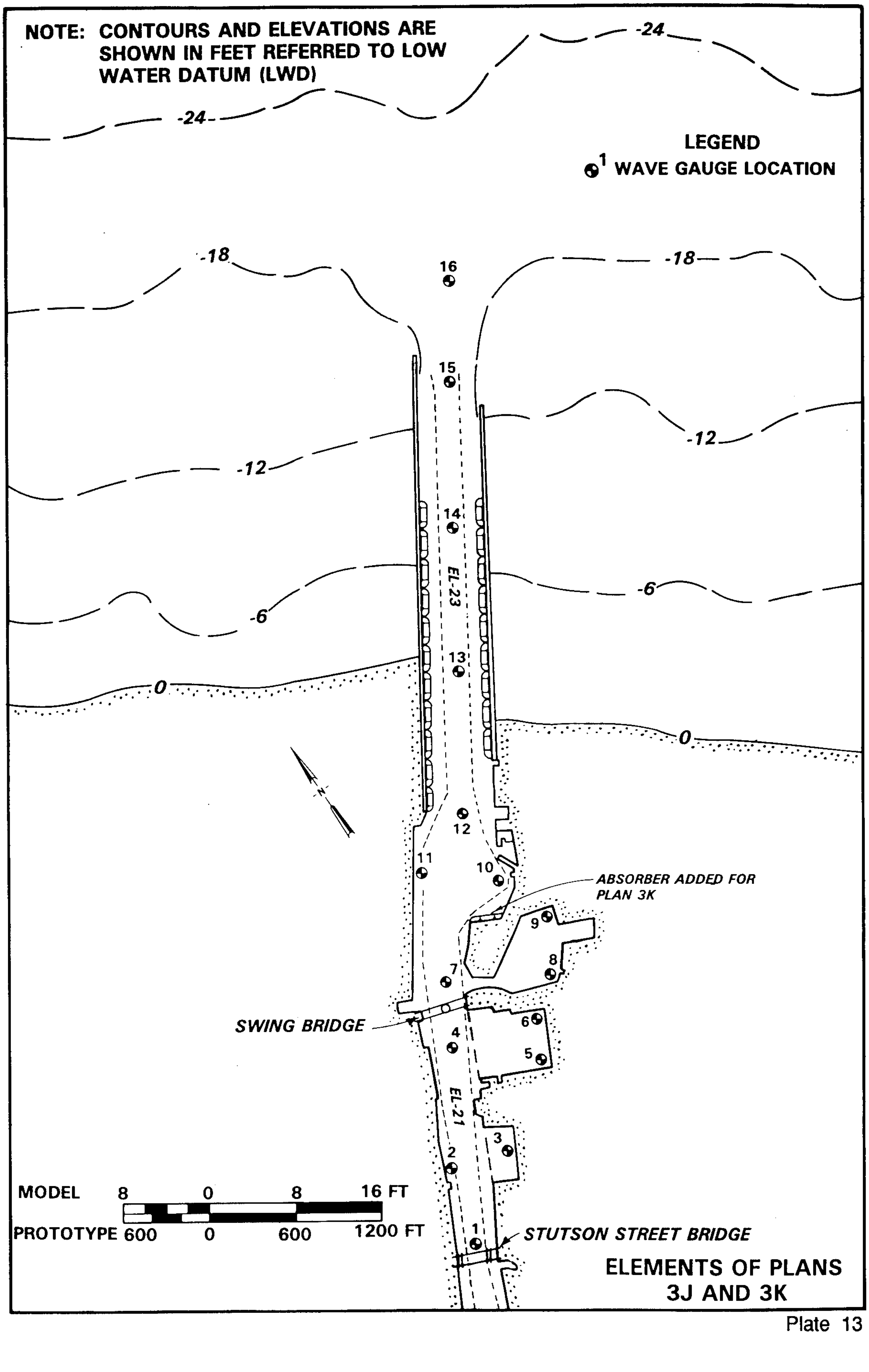
ELEMENTS OF PLAN 3F



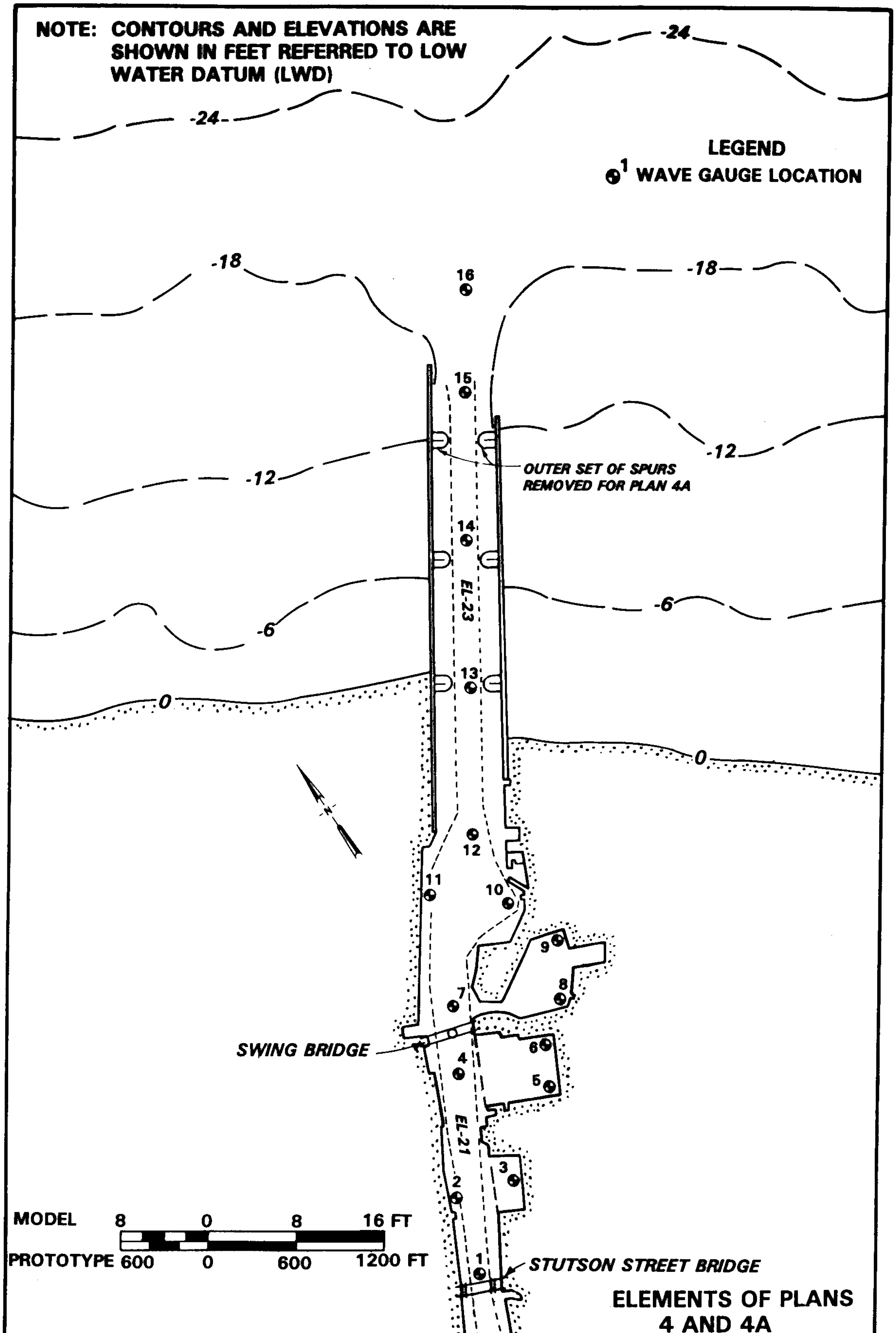
ELEMENTS OF PLANS 3G AND 3H



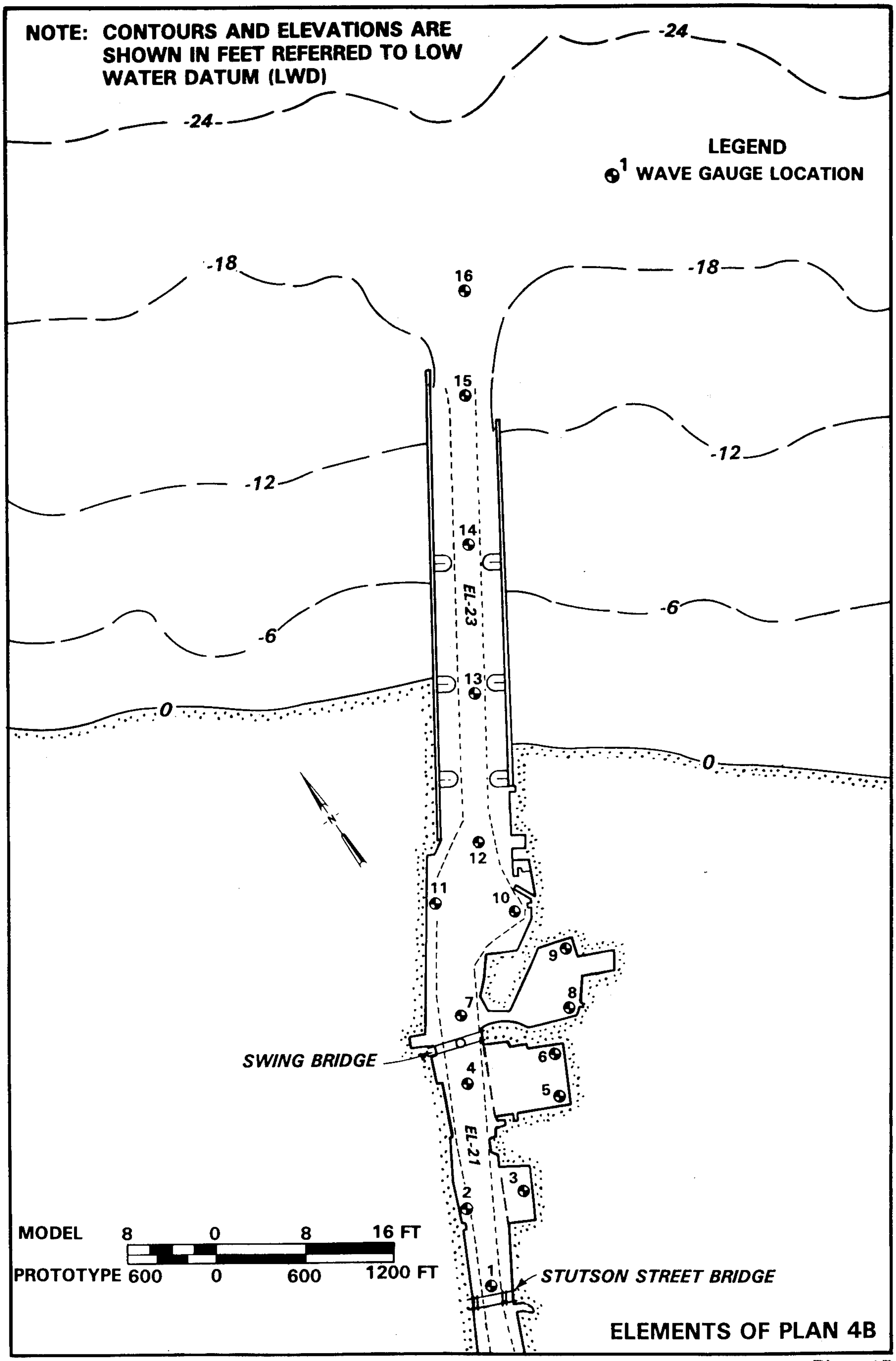
ELEMENTS OF PLAN 3I



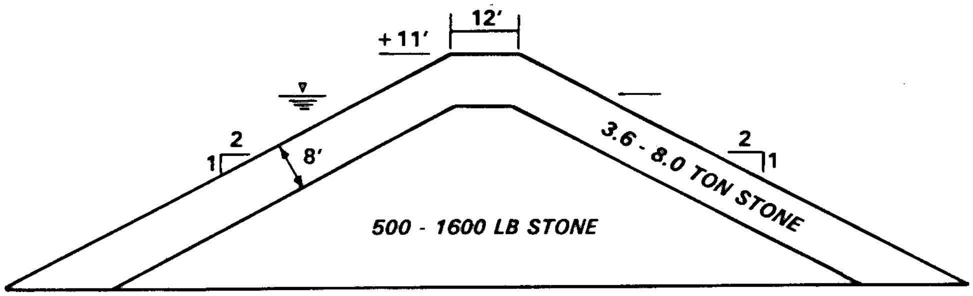
ELEMENTS OF PLANS 3J AND 3K



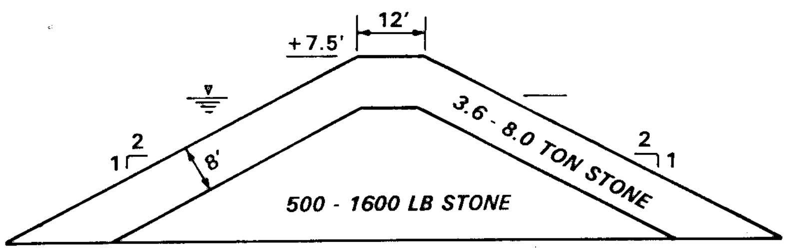
ELEMENTS OF PLANS 4 AND 4A



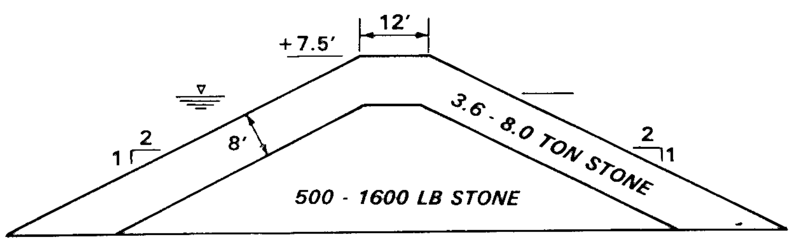
ELEMENTS OF PLAN 4B



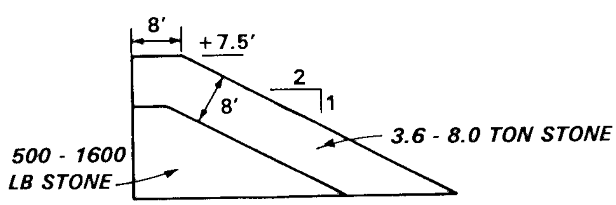
OFFSHORE AND DOGLEG BREAKWATER
PLANS 1-1C, PLANS 2-2A



WEST JETTY EXTENSION
PLANS 1A-1C

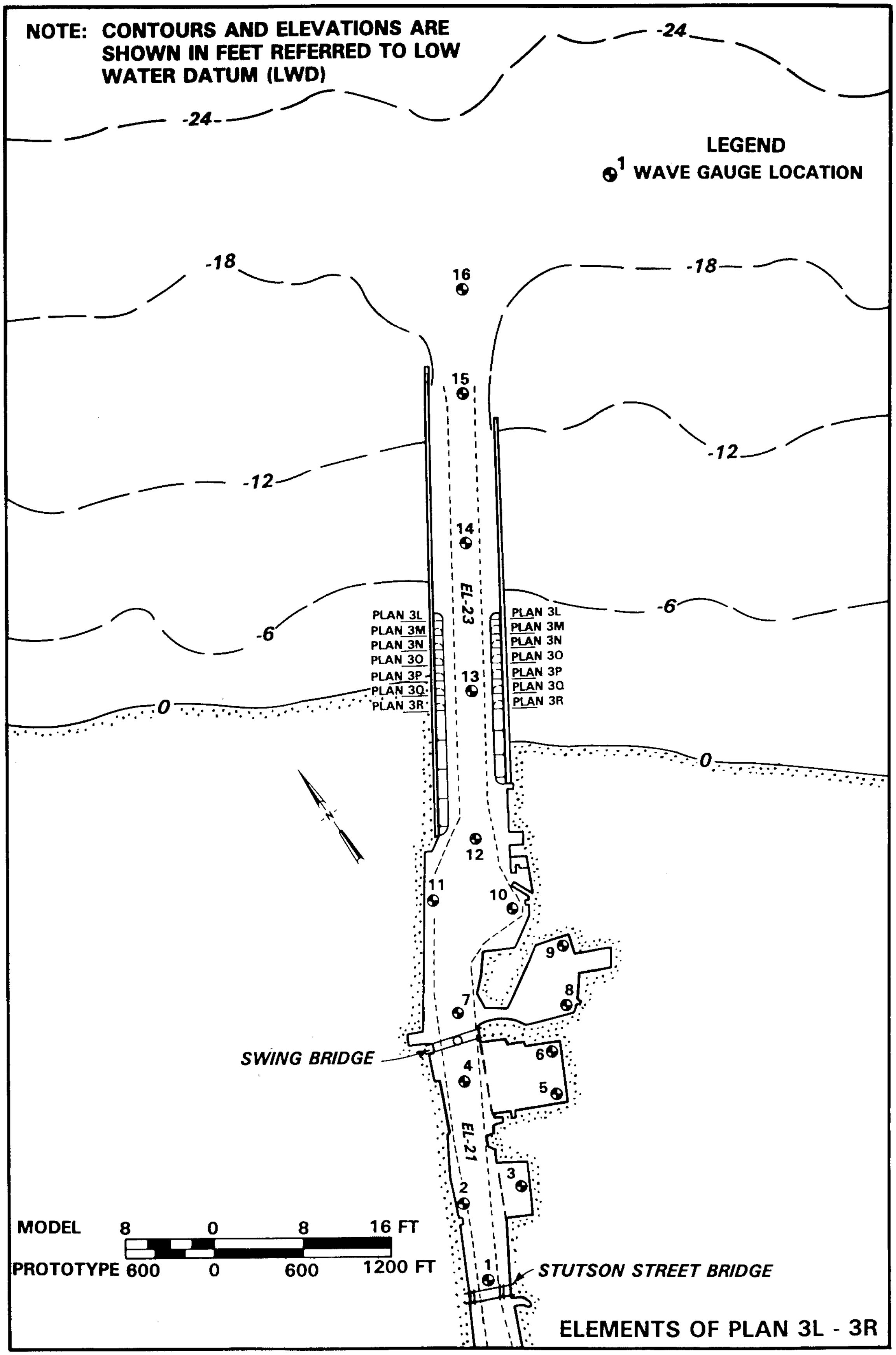


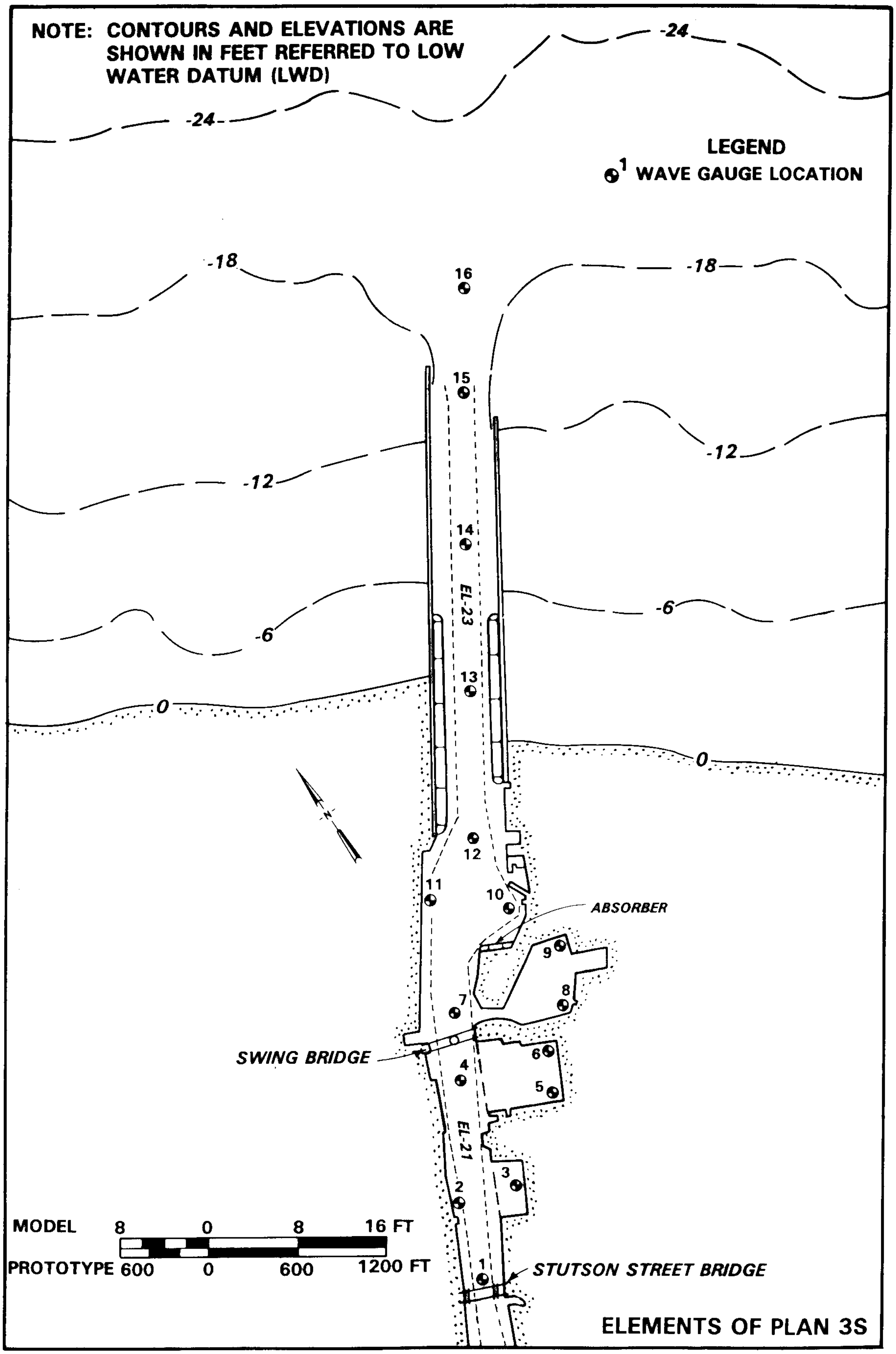
SPUR
PLANS 3C, 3E 3F, 3H, 3I
PLANS 4-4B



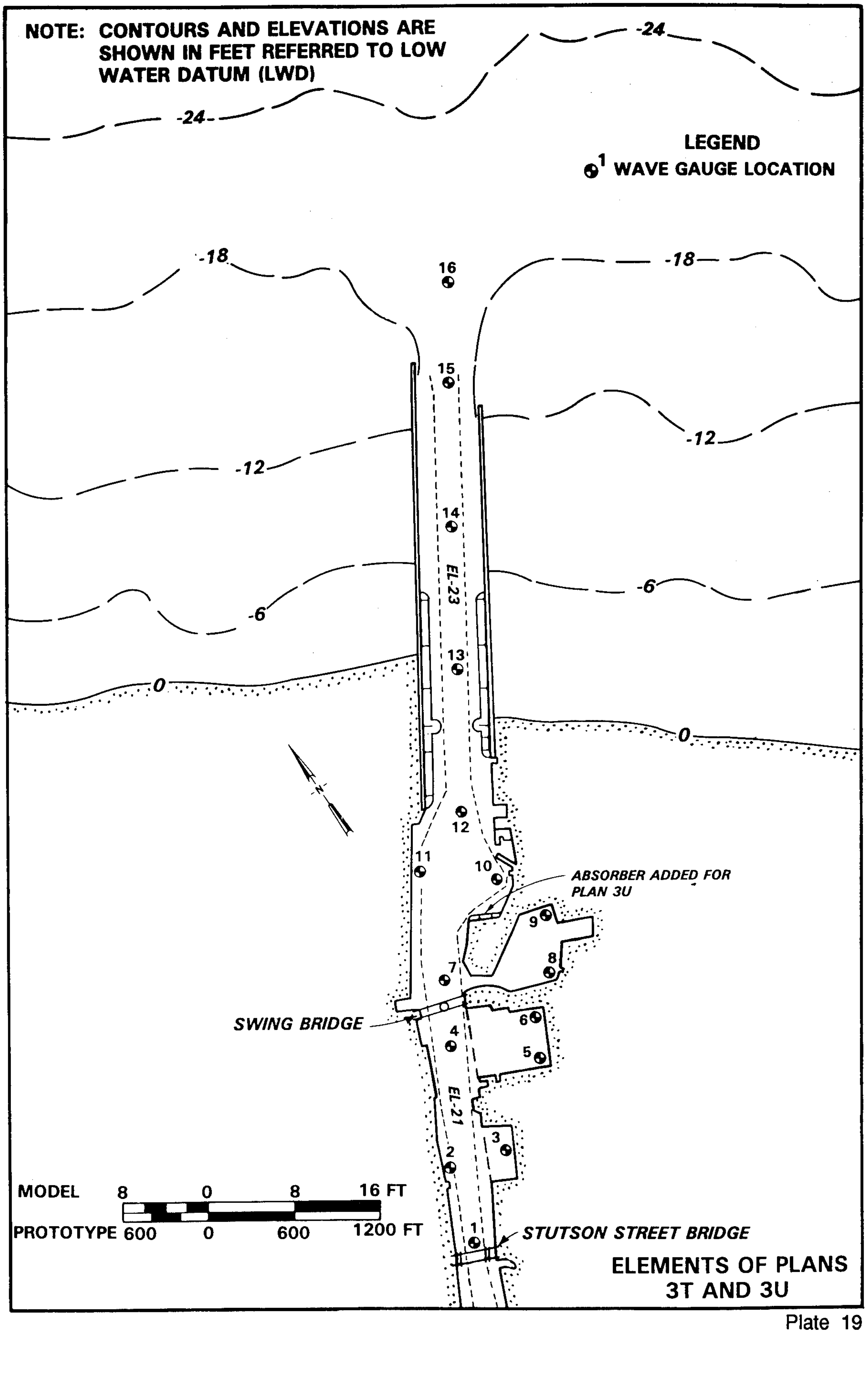
RUBBLE ABSORBER
PLANS 1B-1C
PLANS 2-2A
PLANS 3-3K

TYPICAL STRUCTURE CROSS SECTIONS
INITIAL TEST SERIES

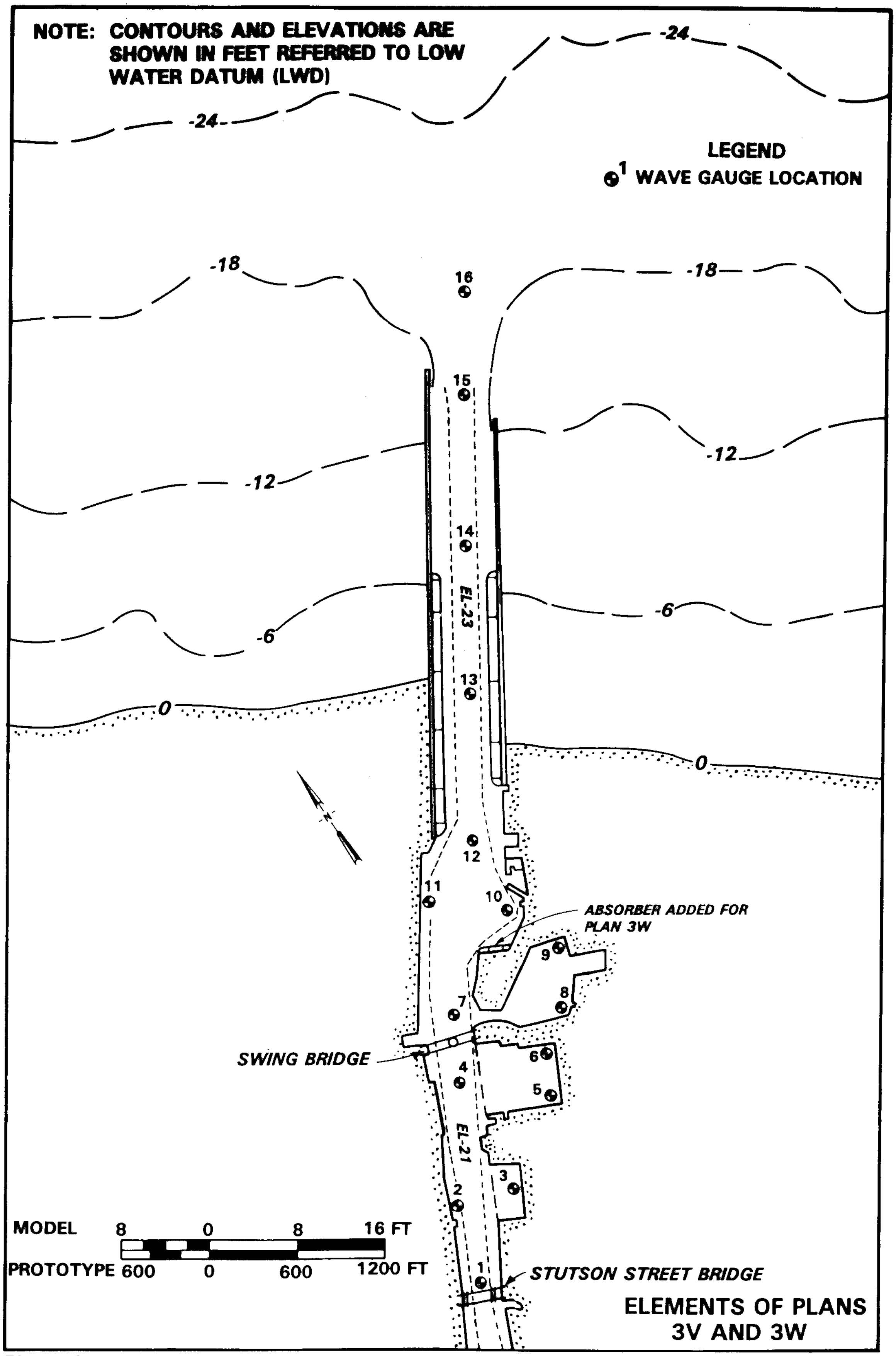

NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
-24
-24
LEGEND
1 WAVE GAUGE LOCATION
-18
-18
16
15
-12
-12
14
EL-23
-6
-6
PLAN 3L
PLAN 3M
PLAN 3N
PLAN 3O
PLAN 3P
PLAN 3Q
PLAN 3R
PLAN 3L
PLAN 3M
PLAN 3N
PLAN 3O
PLAN 3P
PLAN 3Q
PLAN 3R
13
0
0
N
12
11
10
9
8
7
SWING BRIDGE
6
4
5
EL-21
3
2
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
1
STUTSON STREET BRIDGE
ELEMENTS OF PLAN 3L - 3R

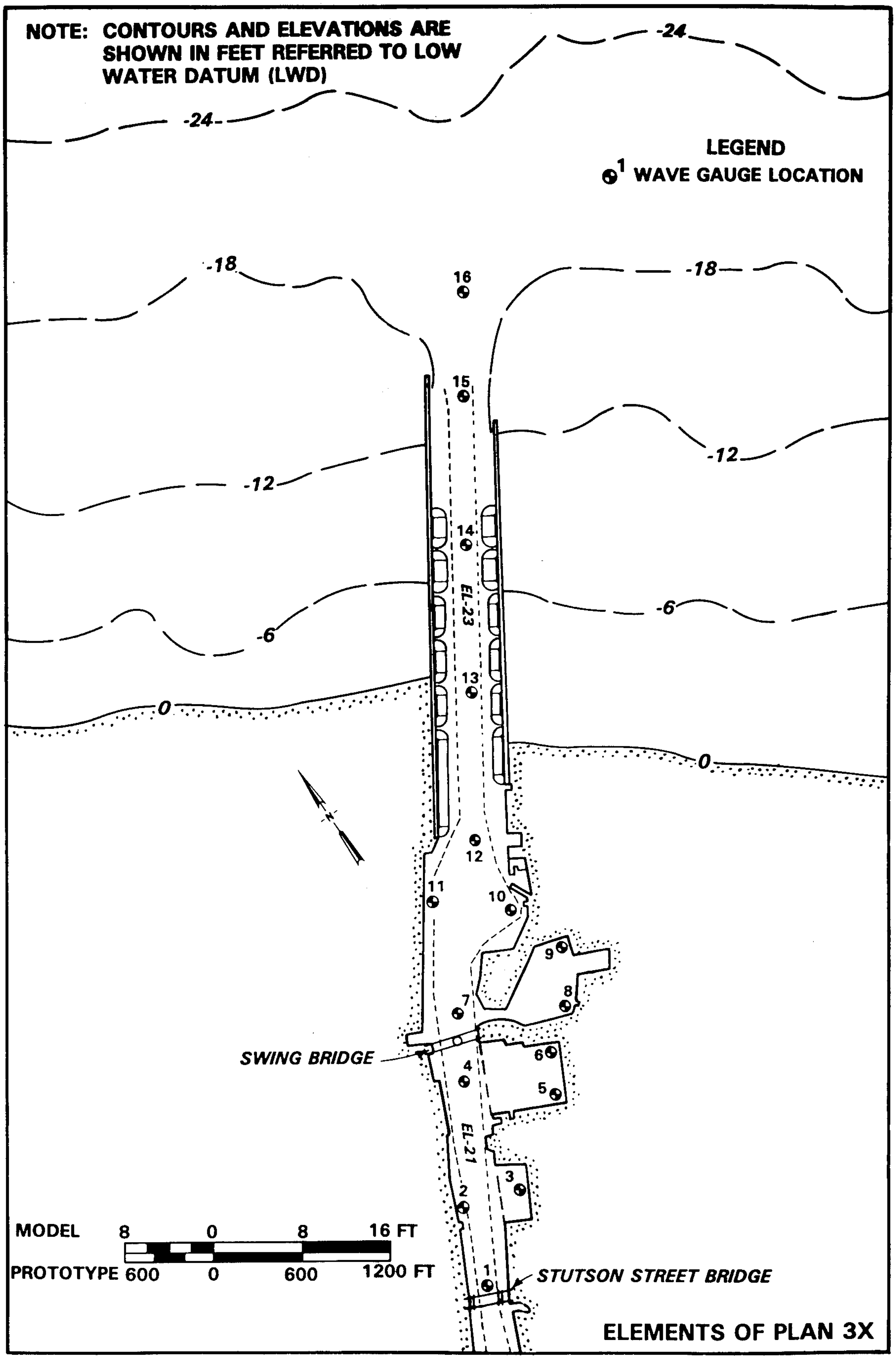


ELEMENTS OF PLAN 3S

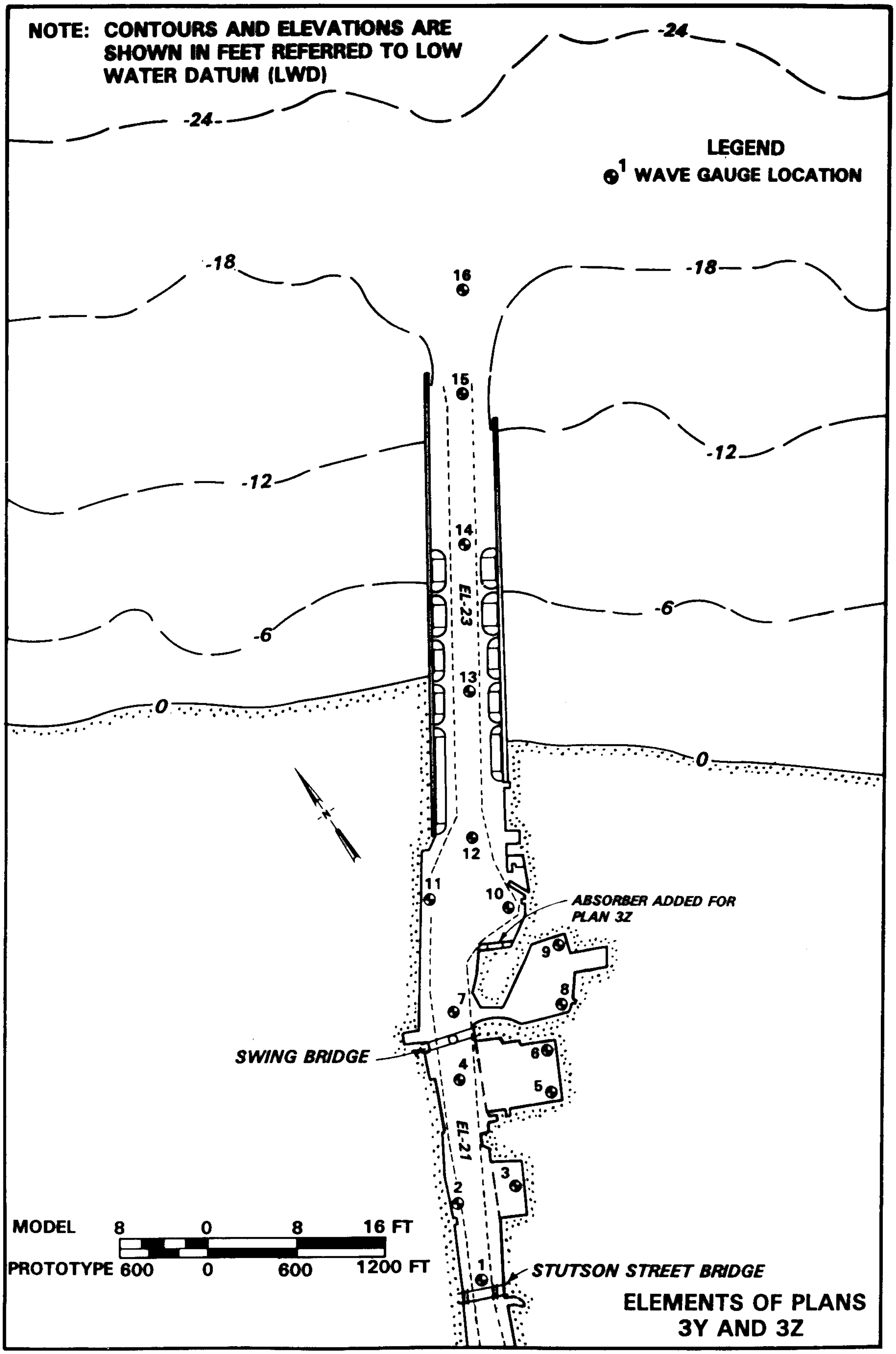


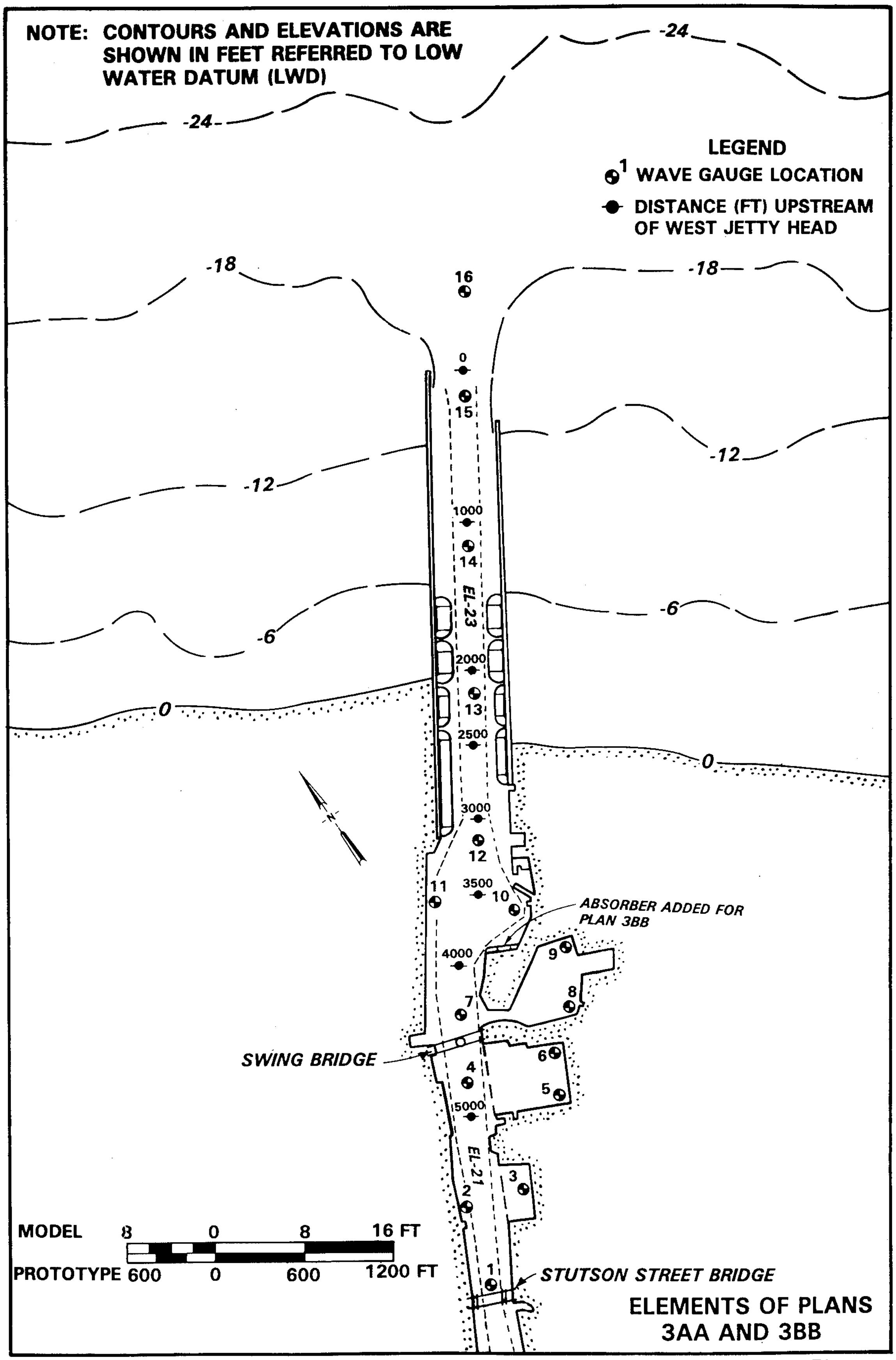
ELEMENTS OF PLANS 3T AND 3U


NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
LEGEND
1 WAVE GAUGE LOCATION
-24
-18
-12
-6
0
EL-23
EL-21
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
ABSORBER ADDED FOR PLAN 3W
SWING BRIDGE
STUTSON STREET BRIDGE
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
ELEMENTS OF PLANS 3V AND 3W

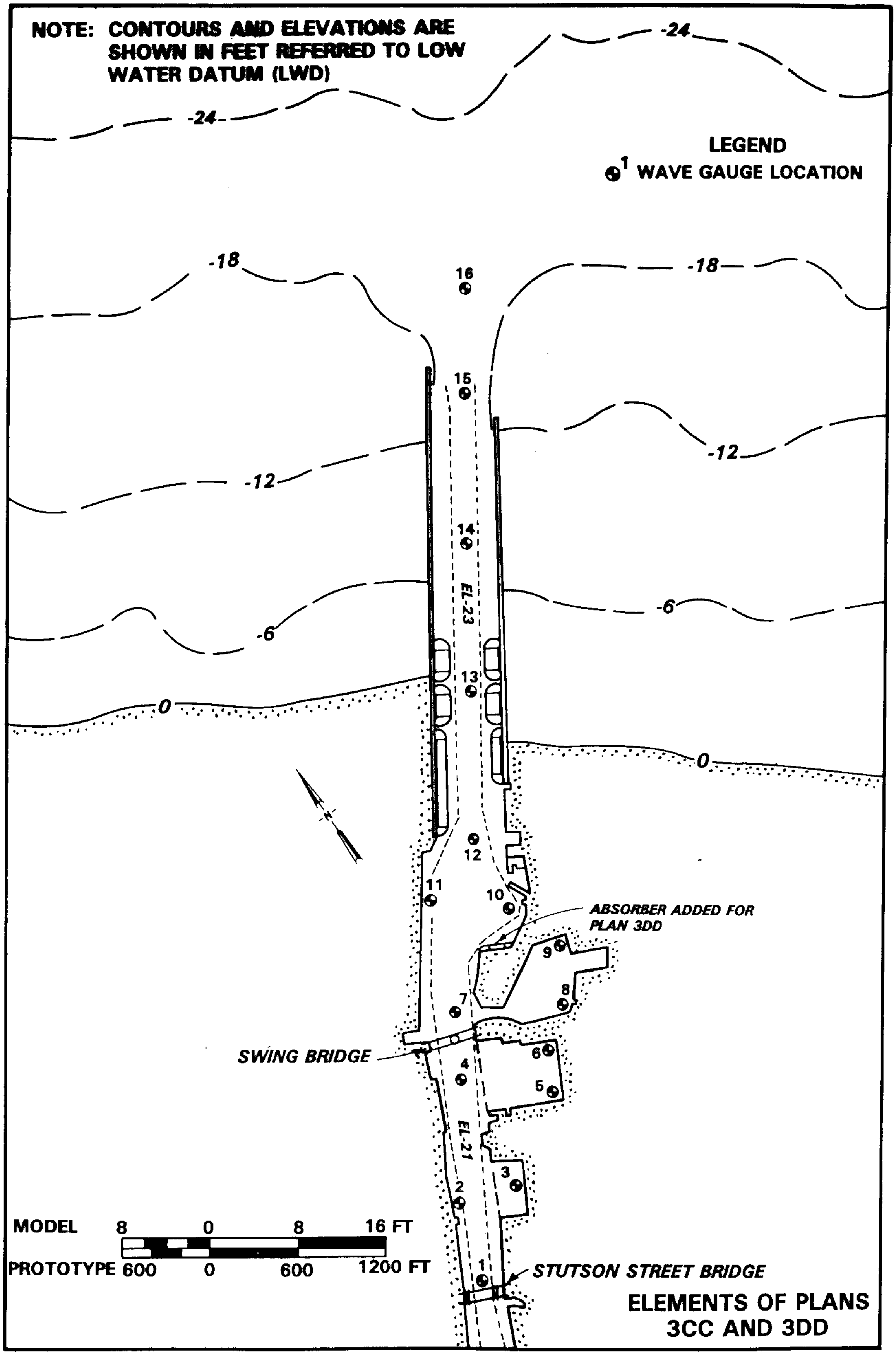


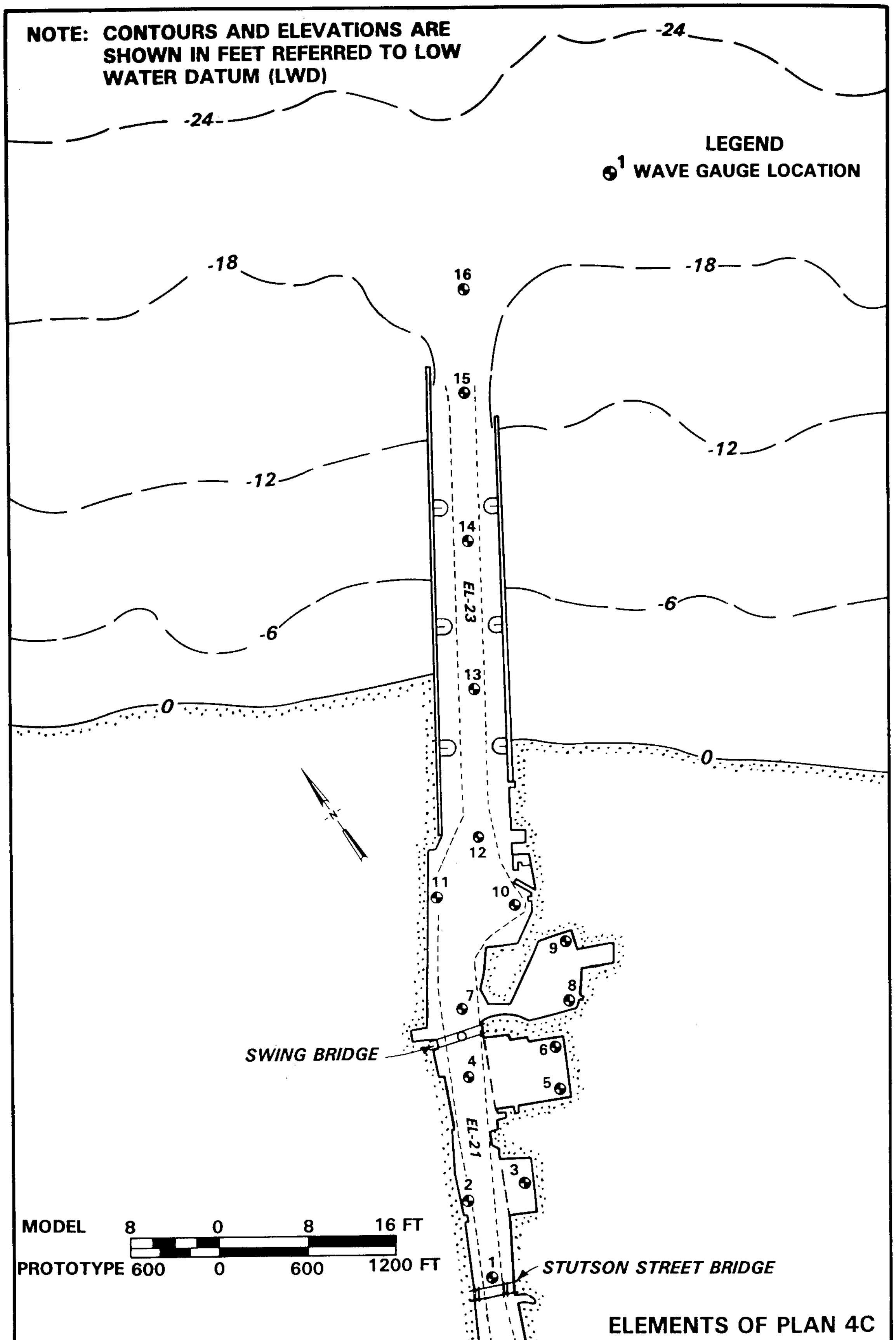
ELEMENTS OF PLAN 3X


NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
LEGEND
1 WAVE GAUGE LOCATION
-24
-18
-12
-6
0
EL-23
EL-21
ABSORBER ADDED FOR PLAN 3Z
SWING BRIDGE
STUTSON STREET BRIDGE
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
ELEMENTS OF PLANS 3Y AND 3Z

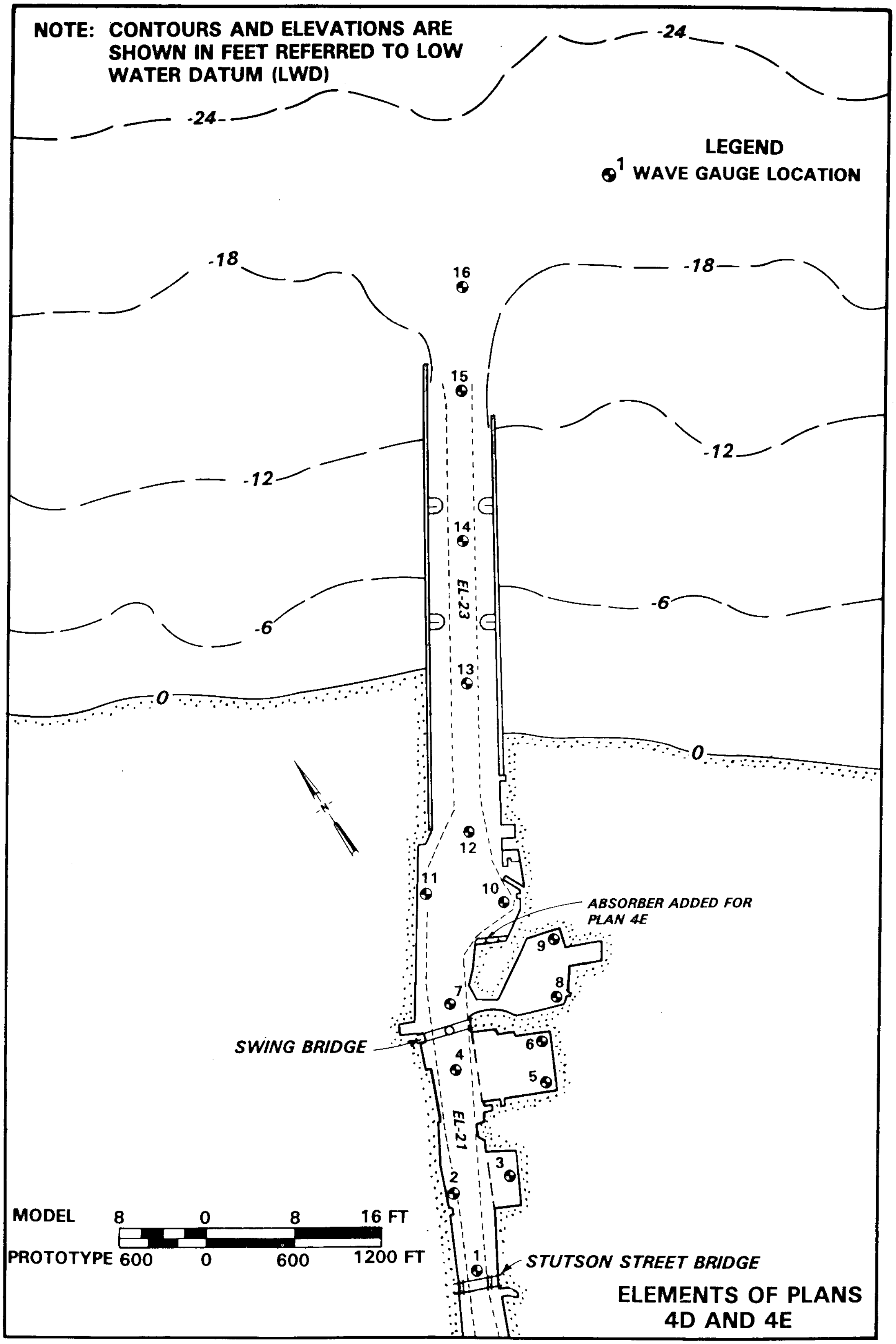


ELEMENTS OF PLANS 3AA AND 3BB

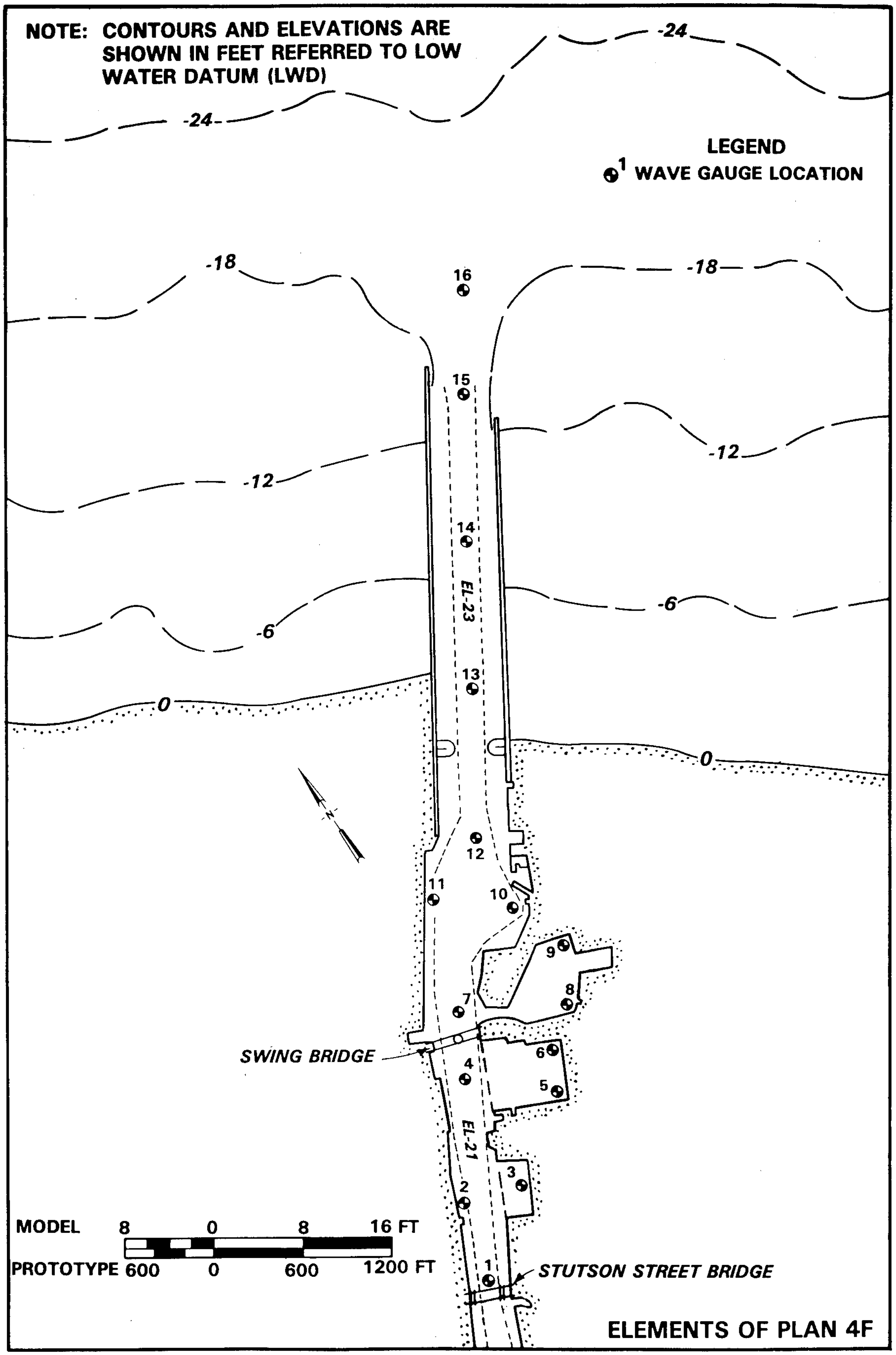

NOTE: CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
LEGEND
1 WAVE GAUGE LOCATION
-24
-18
-12
-6
0
EL-23
EL-21
ABSORBER ADDED FOR PLAN 3DD
SWING BRIDGE
STUTSON STREET BRIDGE
MODEL 8 0 8 16 FT
PROTOTYPE 600 0 600 1200 FT
ELEMENTS OF PLANS 3CC AND 3DD



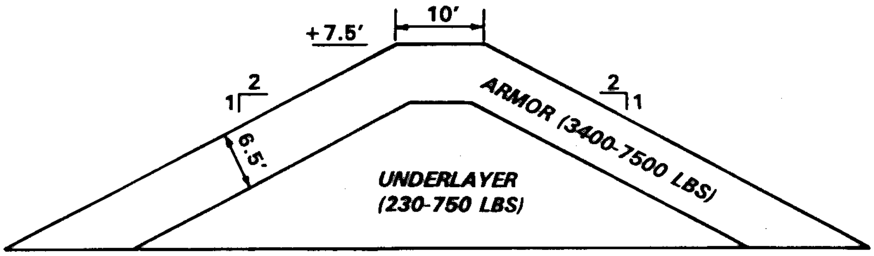
ELEMENTS OF PLAN 4C



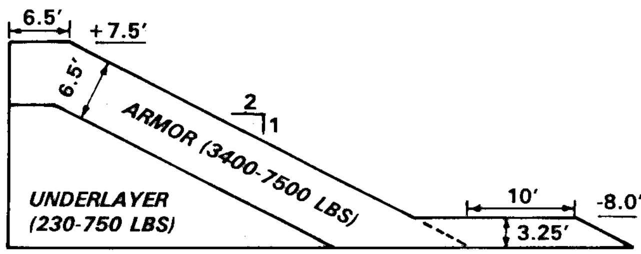
ELEMENTS OF PLANS 4D AND 4E



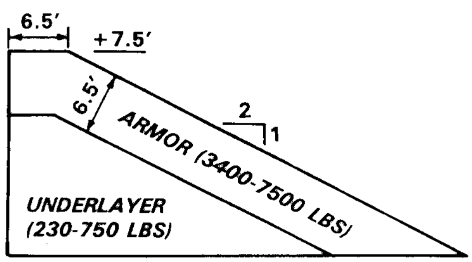
ELEMENTS OF PLAN 4F



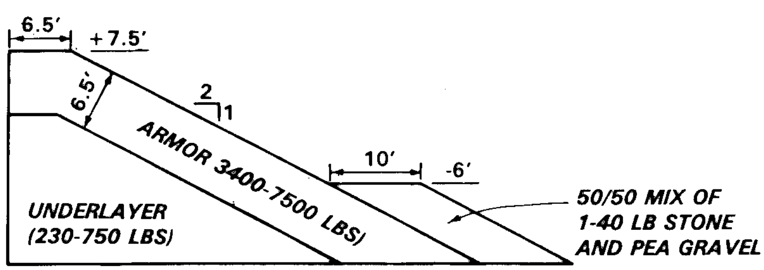
SPUR
PLANS 3T-3U
PLANS 4C-4F



ABSORBER HEAD
PLANS 3L-3DD



ABSORBER TRUNK
PLANS 3L-3BB



ABSORBER ENVIRONMENTAL ENHANCEMENT
PLANS 3L-3DD

TYPICAL STRUCTURE CROSS SECTIONS
REFINED TEST SERIES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1995

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Rochester Harbor, New York, Design for Wave Protection; Coastal Model Investigation

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report CERC-95-7

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Buffalo
1776 Niagara Street
Buffalo, NY 14207-3199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A 1:75-scale (undistorted) three-dimensional hydraulic model was used to investigate the design of proposed breakwater modifications at Rochester Harbor, New York, with respect to wave action at the site. The model reproduced approximately 1,372 m (4,500 ft) of the lower reaches of the Genesee River, the jettied entrance, about 914 m (3,000 ft) of the New York shoreline on each side of the harbor entrance, and sufficient offshore area of Lake Ontario to permit generation of the required test waves. Proposed improvements consisted of a detached breakwater with the entrance oriented to the west, a dogleg breakwater with the entrance oriented to the east, and rubble absorbers and/or spurs installed along the insides of the existing jetties. A 24.4-m-long (80-ft-long) unidirectional, spectral wave generator, an automated data acquisition and control system, a water circulation system, and a crushed coal tracer material were used in model operation. It was concluded from test results that:

a. Existing conditions are characterized by rough and turbulent wave conditions during periods of storm wave attack, aggravated by reflections off the vertical wall linings in the lower reaches of the river. Wave heights in excess of 0.9 m (3.0 ft) occurred in the lower reaches of the river during the navigation season for both initial and refined test conditions.

(Continued)

14. SUBJECT TERMS

Breakwaters	Jetties	Wave absorbers
Harbors, New York	Jetty spurs	Wave protection
Hydraulic models	Rochester Harbor, New York	

15. NUMBER OF PAGES
149

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

b. Of the improvement plans which included an offshore breakwater with the entrance oriented to the west, Plan 1C met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the navigation season for initial test conditions.

c. Both of the improvement plans which entailed a dogleg breakwater and entrance orientation to the east (Plans 2 and 2A) met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the navigation season for initial test conditions.

d. Of the improvement plans which consisted of rubble-mound absorbers and/or spurs along the insides of the existing jetties, Plans 3A and 3F met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the navigation season for initial test conditions.

e. Based on results of initial test conditions, it was determined that the more cost-effective alternatives would consist of some combination of rubble-mound absorbers and/or spurs installed along the insides of the existing jetties.

f. Of the improvement plans which included rubble-mound absorbers, both with and without spurs, along the insides of the existing jetties, Plans 3X, 3Z, and 3BB met the established 0.3-m (1.0-ft) wave height criterion in the lower reaches of the river during the navigation season for refined test conditions.

g. Of the improvement plans which entailed only spurs along the insides of the existing jetties, none met the established wave height criterion in the lower reaches of the river for refined test conditions.

h. Based on results of refined test conditions, the segmented rubble-mound absorber configuration of Plan 3BB was selected as optimum, considering both wave protection provided and costs.

i. Construction of the rubble-mound absorbers between the jetties (Plan 3BB) will have minimal impact on water-surface elevations and river current velocities for the various river discharges.

j. Construction of the rubble-mound absorbers (Plan 3BB) will not alter riverine bed-load sediment movement patterns between the existing jetties.

k. Construction of the rubble-mound absorbers (Plan 3BB) will not alter the movement of the river plume or river surface-currents between the existing jetties or as the flow enters the lake.